Feasibility of land-based aquaculture in the Two Wells to Whyalla regional corridor

Steven M Clarke

Goyder Institute for Water Research
Technical Report Series No. 19/11

www.goyderinstitute.org

Goyder Institute for Water Research Technical Report Series ISSN: 1839-2725

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department for Environment and Water, CSIRO, Flinders University, the University of Adelaide, the University of South Australia and the International Centre of Excellence in Water Resource Management. The Institute enhances the South Australian Government's capacity to develop and deliver science-based policy solutions in water management. It brings together the best scientists and researchers across Australia to provide expert and independent scientific advice to inform good government water policy and identify future threats and opportunities to water security.

The following associate partner led the preparation of this report:

Enquires should be addressed to: Goyder Institute for Water Research
Level 4, 33 King William Street
Adelaide, SA 5000
tel: 08 8236 5200
e-mail: enquiries@goyderinstitute.org

Citation

Clarke, S.M. (2022) *Feasibility of land-based aquaculture in the Two Wells to Whyalla regional corridor.* Goyder Institute for Water Research Technical Report Series No. 19/11.

Disclaimer

Contents

List of Figures

List of Tables

Acknowledgements

Many people have kindly provided information for this report based on their specific area of expertise and/or experience. I would particularly like to thank in alphabetical order:

- Dr Michele Ackeroyd, previous Director, Goyder Institute for Water Research (ground and surface water contacts and information)
- Mr Kriston Bott and Dr Sasi Nayar (algae), Mr Mark Gluis and Prof Xiaoxu Li (shellfish); Assoc Prof David Stone, Mr Aaron Strawbridge and Dr Marty Deveney (finfish); Ms Jane Ham (editing and finalizing the document) and Ms Annie Sterns (document formatting), Aquatic Sciences, South Australian Research and Development Institute (SARDI)
- Ms Rowena Brown, Manager and Ms Tamarind Meara, Project Officer, Aboriginal Partnerships Unit, the Department of Primary Industries and Regions (PIRSA) (Aboriginal heritage and liaison)
- Mr Tony Burfield, Integrated Farming Services (client interest in mulloway aquaculture in the Dry Creek salt ponds; expertise is in horticulture)
- Dr John Carragher, Logifish Consulting, technical consultant to A-Culture Holdings Pty Ltd (inland saline groundwater aquaculture)
- Ms Jade Davison, Senior Advisor, Aquaculture Policy and Dr Kate Rodda, Program Leader, Aquaculture Environment, Fisheries and Aquaculture, PIRSA (general South Australian aquaculture information)
- Mr Andrew de Dezsery, Operations Manager, Aquaculture Advantage, Lewiston, South Australia (aquaponics species, business, and challenges)
- Ms Anna Adell, Lund, Technical University, Sweden (student project on water quality for freshwater aquaculture in the northern Adelaide Corridor, South Australia, supervised by Dr Joanne Vanderzalm, CSIRO in association with the author of this report)
- Dr Stewart Fielder, Senior Research Scientist, Port Stephens Fisheries Institute, New South Wales Department of Primary Industries (freshwater and marine aquaculture)
- Mr Sam Gaylard, Principal Marine Scientist; Mr Tavis Kleinig, Senior Scientific Officer, Hydrogeology; Mr Andrew Pruszinski, Manager Site Containation; and Ms Gabrielle Wigley, Senior Hydrogeologist; Environmental Protection Authority (Northern Adelaide Plains groundwater)
- Mr Mark Hellowell, Mechanical Technology, Muradell Pty Ltd (microalgal production and processing
- Mr Martin Hernen, ex-secretary, South Australian Aquaculture Association (aquaculture and recirculation aquaculture farming of Barramundi)

- Mr Wayne Hutchinson, Project Officer, Fisheries Research and Development Corporation, FRDC
- Dr Brett Ingram, Senior Scientist, Fisheries Management Branch, Victorian Fisheries Authority (freshwater aquaculture), Department of Primary Industries (freshwater aquaculture)
- Mr Jack Lee, Mark Lee Fish Farm, St Kilda, Adelaide
- Mr Ashley Lunn, Market Manager, SAFCOL Central Fish Market (Adelaide seafood wholesale market - species, sale prices and volumes)
- Mr McOmish, Sundrop Farms, Adelaide Office (business development, hydroponics and aquaculture)
- Prof Graham Mair and Prof Jian Qin, Biological Sciences, Flinders University (aquaculture)
- Mr Allan Mathieson, Mine Manager, Buckland Dry Creek P/L (detailed knowledge of the Dry Creek salt ponds and interest in aquaculture development in these facilities)
- Mr Steve Mawer, ex-owner, Southern Barramundi
- Ms Emily Mellor, Senior Projects Officer, Strategic Development and Mr Stephen Dubrich, Manager, Strategic Development, Rural Solutions South Australia, PIRSA (information on the Two Wells to Whyalla Regional Corridor and general aquaculture information)
- Mr Eugene Moore, PhD Candidate, Natural and Built Environments Research Centre, University of South Australia (integrated agri-aquaculture systems)
- Mr Robin Moseby, Managing Director, Bradleigh Manufacturing Pty Ltd, Soldome (aquaculture, polyculture and hydroponics) and ex-President, Inland Aquaculture Association of South Australia (SA inland aquaculture)
- Mr Sergio Rossi, Coordinator GIS and Geoanalytics, Spatial Systems, Primary Industries and Regions South Australia (PIRSA)
- Mr Eric Murray, owner of an Eel and Murray Cod aquaculture venture, Whyalla
- Mr Bryan Robertson, Executive Officer, Hortex (use of groundwater by horticulturists in the Northern Adelaide Plains)
- Mr Andrew Poligerinos, previous Hatchery Manager, Robarra, West Beach, Adelaide
- Mr David Whyte, previous Group Technical Manager, Huon Aquaculture (aquaculture businesses, locations, species and challenges)
- Mr Patrick Tigges, Director, Billund Aquaculture Australia (recirculation aquaculture systems)
- Dr Joanne Vandezalm, Senior Research Scientist, Ground Water & Management, CSIRO Land & Water (Northern Adelaide Plains groundwater)

While not mentioning the names of those involved, I would also like to acknowledge the useful discussions I have had with a number of entrepreneurial groups, including advisors and investors, looking at starting aquaculture developments in South Australia, in some instances within the Two Wells to Whyalla Regional Corridor (2W2W). Such conversations did much to help clarify the nature of the information that was important for their decision-making.

Abbreviations and Acronyms

2W2W – Two Wells to Whyalla regional corridor

AMLNRMR – Adelaide and Mount Lofty National Resources Management Region

CapEx – Capital Expenditure

CoP – cost of production

DAFF – Dissolved Air Flotation and Filtration Plant

DEW – The Department for Environment and Water

EPA – Environmental Protection Agency

FCR – Food Conversion Ratio

FTE – Full-Time Equivalent

HDPE – High Density Polyethylene

HOGG – head on, gilled and gutted

ICI – Imperial Chemical Industries

IMTA – Integrated multi-trophic aquaculture

IRR – internal rate of return

MAR – Managed Aquifer Recovery

MLRNRMR – Mount Lofty Ranges Natural Resource Management Region

N&YNRMR – Northern and Yorke Natural Resources Management Region

NAIS – North Adelaide Irrigation Scheme

NAP – Northern Adelaide Plains

NAPAI – Northern Adelaide Plains Agribusiness Initiative

NPV – net present value

N-PWRA – Non-prescribed Water Resources Areas

NSW – New South Wales, Australia

NSW DPI – NSW Department of Primary Industries

NT – Northern Territory, Australia

OpExp – Operating Expenditure

PHES – Pumped hydro energy systems

PIRSA – Department of Primary Industries and Regions

PLC - Programmable Logic Controller

PM – profit margin

PWRA – Prescribed Water Resources Area

QLD – Queensland, Australia

R&D – research and development

RAS – Recirculation Aquaculture Systems

RDA – Regional Development Australia

SA - South Australia, Australia

SAFCOl – South Australian Fishermans Co-Operative Limited

SARDI – South Australian Research and Development Institute

SWOT – Strengths, weaknesses, opportunities and threats

TAFE – Technical and Further Education

TAS – Tasmania, Australia

TDS – Total Dissolved Solids

UAE – United Arab Emirates

UK – United Kingdom

USA – United States of America

VIC – Victoria, Australia

VPS – Virginia Pipeline Scheme

WA – Western Australia, Australia

WSSV – white spot syndrome virus

WWTP – Wastewater Treatment Plant

Executive Summary

The potential for land-based aquaculture to create new economic and employment opportunities on the coastal plain between Two Wells, about 40 km north of Adelaide, South Australia, and Whyalla on the north-western side of Spencer Gulf (hereafter, referred to as Two Wells to Whyalla Regional Corridor or 2W2W) has been investigated.

The investigation involved a literature/data review, ground-truthing and communication with many people with relevant specialised knowledge. The project addresses the nature of past and existing aquaculture ventures, the broad type of aquaculture technologies potentially suitable for use, the aquaculture species of interest, the nature of the water sources and environment in the region, and highlights a number of potential aquaculture opportunities, presenting economic and sensitivity analyses on some of these.

The region is characterised by a dry temperate climate, becoming increasingly arid to the north. Due to low rainfall and high evaporation rates, there is little surface freshwater or potential for freshwater pond aquaculture. While the region includes a number of larger country cities and towns compared to other regions in South Australia, and some coastal areas are becoming increasingly popular tourist destinations, much of it is sparsely populated. A number of the larger population centres and a few areas associated with mining and/or processing have localised pollution issues that affect small areas of soil and groundwater.

Reticulated water occurs across much of 2W2W, with the spatial extent of recycled water expanding to enable increased horticulture production. Reticulated water is, however, expensive to use and can have less than ideal water quality for aquaculture. Subsurface groundwater is available across much of the region and is a potentially important resource for aquaculture. However, its quality, in particular salinity, is variable with bore location and depth, and the quantity available is typically limited due to low aquifer recharge rates and its existing utilisation, primarily for crops and livestock.

While much of the coastal area of 2W2W is characterised by farming land, there is also considerable area that has high environmental significance with samphires, mangroves, mud flats and seagrasses providing important breeding and feeding habitat for a wide range of birds and fishes.

From an assimilation of the relevant information, a number of aquaculture business opportunities are identified and described. The primary ones are:

- The use of intensive recirculation aquaculture systems (RAS), which enables biosecurity and water temperatures to be optimised to farm:

  - Barramundi (estuarine) to grow this existing land-based South Australian industry sector;
  - Yellowtail Kingfish (marine) to diversify this South Australian industry sector from its present reliance on growout in cages in the sea at ambient temperatures to an onshore system where the environment can be controlled; and
  - Murray Cod (freshwater), to develop an almost non-existent industry sector in South Australia for a species with an iconic status for marketing and a declining supply from the wild. These species are suggested because they have an existing moderate to high market value and acceptance; local, national and international markets exist; and there is a moderate amount of biological and basic aquaculture related information available (although not for intensive RAS systems, except for Barramundi).

  To potentially increase profitability, diversify business risk and enhance environmental stewardship it may be possible for the core aquaculture business to be supplemented by effective use of the nutrient enriched wastewater from the RAS for other purposes, with fresh wastewater having the greatest potential of being suitable for horticulture (aquaponics) and/or agriculture. The benefits of this have been increasingly demonstrated at commercial operations overseas.

  The key challenges to the development and success of land-based aquaculture have been identified as the potential high cost of such systems; the lack of specific biological and economic information relating to the species recommended for farming in such systems; the limited hands-on ‘world’s best practice’ knowledge for establishing and operating such systems; the local availability of cheap hatchery produced fish for stocking the RAS; and the challenge of maintaining a satisfactory market price as the production of a species increases, particularly for species where existing markets are not well developed.

- The use of seawater filled ponds to farm Mulloway, a temperate, native, estuarine species that has been well researched. This species grows rapidly to a reasonable size, has a moderate market price and consumer acceptance, and has been farmed in Australia by a few businesses. Two preferred sites have been identified for the culture of this species, one within 2W2W near Port Broughton and the other just south of 2W2W at Dry Creek, offering development potential, both adjacent to gulf waters and with existing access to saltwater. They have also both been previously impacted by past activities that utilised the ponds; the former for aquaculture and latter for salt production, so developmental approval would likely be consistent with past uses and impacts.

To potentially increase profitability and diversify business risk it may be possible for the core semi-intensive aquaculture business to be supplemented by offering an enhanced fishing experience for recreational fishers by incorporating 'put' and 'catch' ponds. It may also be further enhanced by incorporating environmental tourism and education aligned with the establishment of an integrated biosystem approach to the aquaculture, and promotion and viewing of the natural characteristics of the adjacent samphire, mangrove, mud flat and seagrass ecosystems. If finfish aquaculture is initiated, seaweed culture could potentially be used to assimilate nutrients from the discharge water, with potential to develop products and markets for the seaweed produced. Polychaete worm culture might similarly be undertaken to assimilate organic matter in the sediments. Baitfish and aquaculture feed markets exist that could accommodate such product.

The key challenges to the development and success of Mulloway pond culture have been identified as the negative effects of winter water temperature on Mulloway growth; bird predation during the growout of juvenile Mulloway in ponds; the absence of locally available hatchery produced fish for stocking the ponds; and the largely unknown effect of increased supplies of farmed Mulloway on the markets. The lack of site-specific data relevant to such a venture means that any such development should be undertaken cautiously, starting small and slowly expanding.

- A multi-species hatchery, ideally with access to fresh and saline water, and sited close to transport facilities. To target the provision of early-stage juvenile finfish species, particularly Barramundi and Murray Cod, which have both national and overseas markets, but also potentially such species as Black Bream and Mulloway (estuarine), King George Whiting (marine) and Murray Cod and Silver Perch (freshwater) for stock enhancement of land-based and coastal waters to enhance fishing, and for supply to local aquaculturists as the aquaculture industry continues to grow in South Australia and nationally.

A number of more speculative and/or longer-term opportunities have also been highlighted for land-based aquaculture in 2W2W. These include the production of biomass that can be processed into higher value bio-products such as animal feeds, cosmeceuticals, functional foods and nutraceuticals (e.g. macro- and microalgae, polychaete worms and insects). Another opportunity is the potential to incorporate land-based aquaculture with horticulture, specifically aquaponics. While a recent growth industry in Europe and the United States of America (USA), its development in South Australia is considered to be presently inhibited by a number of factors that are only likely to be overcome through directed actions to build the confidence of existing horticulturists to invest in such activities.

Pumped hydro-energy, a novel approach to power generation in South Australia and only presently in the planning stage, has also been identified as an area to explore for associated aquaculture opportunities.

This report emphasises that aquaculture has been, and will continue to be, a major growth sector for primary industries in South Australia, but that it is also a high-risk investment. The key risks relate to the limited information that exists for many species and culture systems, particularly at commercial scale (biological, environmental, technological and markets) and because some environmental events and/or system failures can cause high mortality of farmed animals very rapidly (in the order of hours, rather than days or weeks). Also, while business plans can be found in the literature and on-line for various scenarios most are based on many assumptions, populated with data from research rather than commercial operations, and are often quite specific to the situation they describe. The production data and proven business plans of established businesses are typically commercially guarded and rarely available for general use.

Please note that the information and data presented in this report relates to the period up to 2016/17.

1. Introduction

1.1. Policy context

This project examines the feasibility of developing aquaculture in the "Two Wells to Whyalla Regional Corridor" (2W2W, Figure 1.1), a region where a number of past (e.g. Attorney-General's Department 2017) and present South Australian Government initiatives have been implemented to address major structural changes to its key businesses (e.g. agriculture, car manufacturing, power generation, mining and ore processing, steel manufacturing, and transport). A number of initiatives with relevance to this project include:

- A Regional Roads and Infrastructure Fund to maintain and improve the performance of regional and remote transport networks.
- Regional Development Australia (RDA) to enter into longer term agreements with the RDA Boards providing funding certainty for the next four years and encourage collaboration between them to undertake work on a wider range of cross-regional issues and economic development projects.

The program is also closely aligned with the South Australian Government's Northern Adelaide Plains Agribusiness Initiative (NAPAI). This initiative is focused on coordinating efforts to expand the agribusiness and food sectors in the Northern Adelaide Plains (NAP), a region that generates over one-fifth of South Australia's horticulture production valued at over $313 million per annum in 2016-17 (PIRSA 2017a). It includes 2W2W to the north, which includes an important diversified industrial manufacturing and processing hub, with associated energy, transport, and logistics support industries (PIRSA 2017b).

.

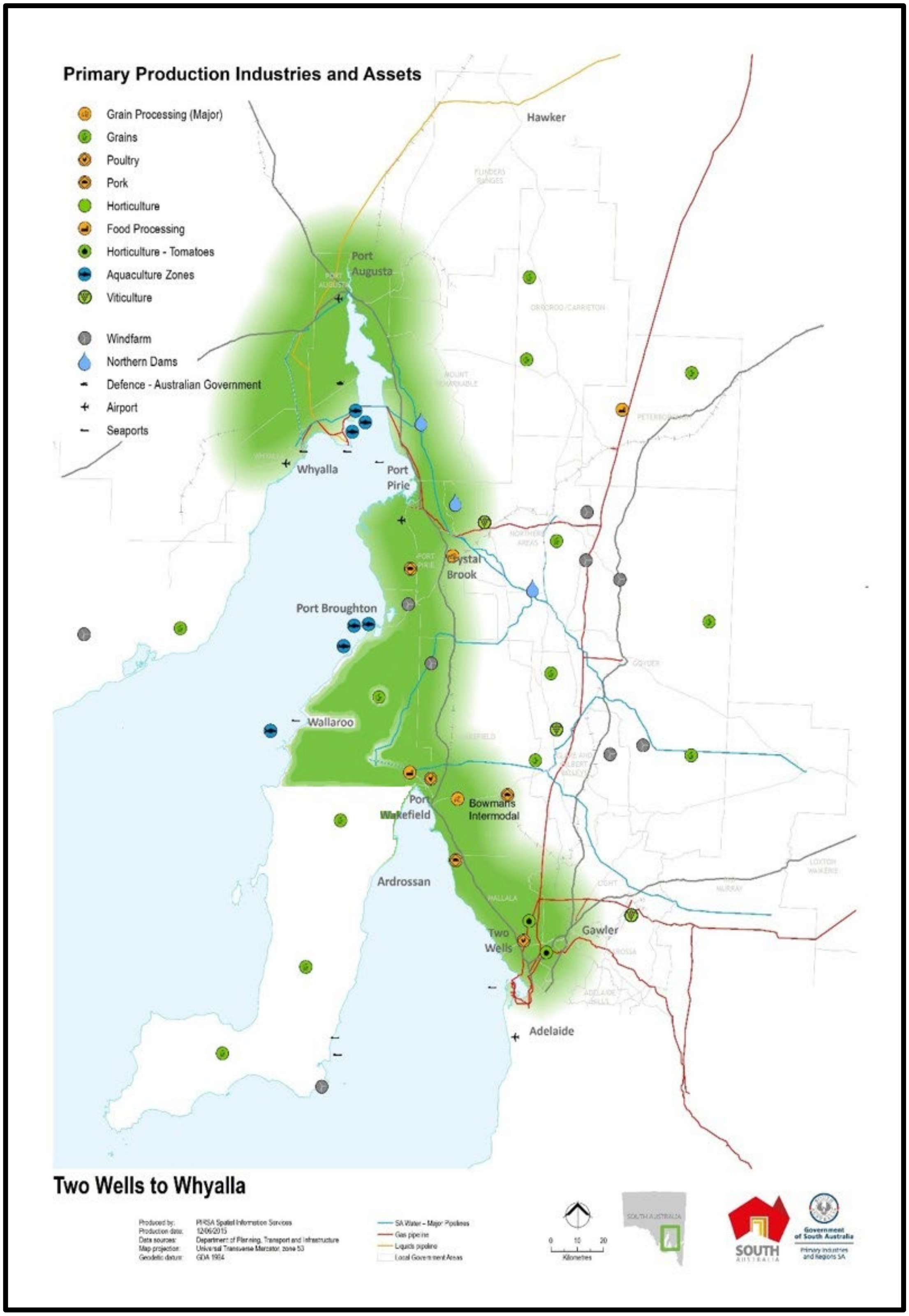

Figure 1.1. Approximate location of the Two Wells to Whyalla Regional Corridor (2W2W), the region of this study shown in green (source: Rural Solutions SA, PIRSA).

While the NAPAI is focused on enhancing primary production, the Northern Adelaide Food Park initiative is focused on co-locating food and beverage manufacturers and processors, and related businesses and service providers, to a centralized point that will benefit from shared infrastructure and services (e.g. food distribution, packaging, processing and waste management).

Aligned with these primarily agriculture and food initiatives, is this project, "Feasibility of land-based aquaculture in the Two Wells to Whyalla regional corridor", which targets aquaculture, a specialised area of primary industries that has been widely identified as a past and potential future key area of growth globally, nationally and in South Australia. Over the last 25 years, aquaculture in South Australia has grown in farm-gate value from about $1 million to $228 million per annum (Econsearch 2016), and while in the last few years growth has slowed in response to the difficult international and local economic climate and the effects of a disease spreading in Australia (Pacific Oyster Mortality Syndrome), there continues to be a strong expectation that aquaculture will grow and that South Australia is well placed to capitalise on this. The challenge is to identify the best opportunities; an alignment of optimal sites, species, production systems and profitability; and how to move these forward to large-scale commercial reality through facilities that have the capacity for high volume and/or high value turnover.

Please note that the information and data presented in this report relates to the period up to 2016/17.

1.2. Objectives

The objective of this project is the identification of tangible land-based aquaculture opportunities in 2W2W, particularly those that can be large-scale and have the capacity for high volume and/or high value turnover. The objective of the project was to focus on opportunities that can be developed within a relatively short time frame, rather than over many years. As such, the short-term opportunities identified here may differ from priority opportunities over a longer timeframe.

1.3. Two Wells to Whyalla Regional Corridor (2W2W)

The 2W2W (Figure 1.1) encompasses the 340 km of coastal plain that stretches northwards from Two Wells (about 40 km north of Adelaide along Highway A1 and with a 2011 population (pop.) of about 2,300, Australian Bureau of Statistics 2016); past Port Wakefield (100 km north of Adelaide, pop. 600) at the northern extent of Gulf St Vincent and Port Pirie (230 km, pop. 10,000) on the north-eastern side of Spencer Gulf; to Port Augusta (310 km, pop. 13,500) at the northern extent of Spencer Gulf; and then south along the northwest side of upper Spencer Gulf to Whyalla (380 km, pop. 22,000) on the west coast of Spencer Gulf. At Two Wells in the south the coastal plain extends inland from about Middle Beach, Gulf St Vincent in the west, to the city of Gawler (43 km, pop. 24,000) about 30 km to the east, whereas in the north it extends inland only about 10 km to the east from Port Pirie – Port Augusta.

The 2W2W is largely contained within the larger Northern and Yorke Natural Resources Management Region (N&YNRMR), which extends from north of Port Augusta to include all of Yorke Peninsula, but on the eastern side of Gulf St Vincent only to an east-west line from approximately Light Horse Plains to Kapunda. It includes the councils: Adelaide Plains, Wakefield Regional Council, District Council of Copper Coast, District Council of Barunga West, Port Pirie Regional Council, District Council of Mount Remarkable, Port Augusta City Council, and City of Whyalla.

To the south of the 2W2W is the NAP, which is within the Adelaide and Mount Lofty National Resources Management Region (AMLNRMR), and a major producer of fresh food in South Australia, particularly horticulture produce. The NAP encompasses a region along the coast from about Port Adelaide in the south to just north of Middle Beach where the Light River discharges to Gulf St Vincent. Its coastal plains area is primarily within the councils of the City of Playford, City of Salisbury and Light Regional Council (Goyder Institute 2016a).

2. Aquaculture

2.1. Status

Aquaculture, the farming of aquatic organisms for the purposes of business, trade or research, will play an increasingly important role globally in meeting the demand for seafood, as nearly all wild-caught fisheries are close to or exceeding their production limits (FAO 2018a). Worldwide, expectations are that by 2030 aquaculture will produce 54% of global seafood production, a 7% increase from 2016 (FAO 2018b). In Australia, aquaculture production grew by 53% and the value of aquaculture production increased by 32% from 2006/07 to 2016/17 (ABARES 2018). South Australia produced 22.8% of Australia's aquaculture production and 17.1% by value in 2016/17, second only to Tasmania (ABARES 2018). South Australia's total value of seafood production (landed) in 2016/17 was $484.5 million, of which aquaculture contributed $231 million (48%) and wild catch fisheries $254 million (52%) (Econsearch 2018). South Australia's aquaculture production rose steadily from 1999/2000-2008/09, doubling in value, but then declined to 2013/14 after which it returned to 2008/09 levels.

In South Australia a diverse range of species are aquacultured, with the largest single industry sector (Southern Bluefin Tuna) accounting for almost 50% of the State's gross value of aquaculture production in 2016/17. Other key sectors include Oysters (17%), Marine Finfish (12%,) Other Species (e.g. aquarium trade species, freshwater finfish, microalgae; 11%) and Abalone (6%) (Econsearch 2018).

South Australia's aquaculture industry created an estimated 955 Full-Time Equivalent (FTE) jobs (594 on-farm and 361 in downstream activities) through direct employment and 1,196 flow-on jobs, giving total employment of 2,151 FTE in 2016/17, with 63% of these jobs in the regions (Econsearch 2018).

Land-based aquaculture involves the farming of freshwater, estuarine, marine and hypersaline aquatic species on land, as compared to in the sea. In South Australia land-based aquaculture is the most diverse of the aquaculture industry groups recognised by the Department of Primary Industries and Regions (PIRSA), the SA Government department responsible for regulation of aquaculture in South Australia (PIRSA 2017d). Species farmed included freshwater and marine finfish, freshwater crayfish, microalgae and marine molluscs. In 2016/17, there were 99 land-based aquaculture licences in South Australia, comprising private businesses, hatcheries (abalone, oysters and finfish), educational and research facilities, as well as tourism and hobby farm businesses (PIRSA 2019).

Land-based aquaculture licensees are located across South Australia, including the regions of Eyre Peninsula, Yorke Peninsula, Kangaroo Island, Adelaide Hills, Riverland and Southeast. Farming systems used include outdoor static and flow-through ponds, and enclosed flow-through or recirculating tanks and raceways. Broodstock, hatchery and live feed systems, of which there are a number, are typically enclosed with flow-through and recirculation capacity for the various holding systems used.

In 2016/17, the land-based aquaculture sector in South Australia produced approximately 3,827 tonnes with an approximate value of $30.9 million (12.3% of total value); the major species being microalgae (in particular the green algae *Dunaliella salina*), Barramundi (*Lates calcarifer*), freshwater crayfish (Yabby - *Cherax destructor* and Marron - *Cherax tenuimanus*) and Rainbow Trout (*Oncorhynchus mykiss*). Other species farmed included Greenlip Abalone (*Haliotis laevigata*), Pacific Oyster (*Crassostrea gigas*), Native Oyster (*Ostrea angasi*), Yellowtail Kingfish (*Seriola lalandi*), Murray Cod (*Maccullochella peelii peelii*), Brown Trout (*Salmo trutta*), Silver Perch (*Bidyanus bidyanus*), Golden Perch (*Macquaria ambigua*), Barcoo Grunter (*Scortum barcoo*), and Eels (*Anguilla spp*.), as well as a variety of ornamental aquarium species and other microalgae species (PIRSA 2019).

An estimated 44 FTEs were directly employed by the land-based aquaculture sector with an additional 83 FTE employed as a result of flow-on activities such as transport and retail (PIRSA 2019).

In 2W2W, aquaculture is presently very limited with only a small aquaponic venture at Lewiston in the south-east, a small recirculation Eel and Murray Cod venture in Whyalla, and a small microalgal pond based research and development venture and large microalgal pond production venture to the north-east of Whyalla. In the past, however, this region has been the location of several aquaculture ventures, including:

- South Australia's first Pacific Oyster hatchery and growout operation, which was initiated by Imperial Chemical Industries (ICI) in its salt production ponds, that stretched for some 30 km along the coast north of Port Adelaide. Juvenile oysters (spat) were sourced from Tasmania in 1974 and Scotland in 1976, placed on wires (about 10 to the wire) on wooden racks in the first pond of about 352 ha, which received tidally pumped water from Chapman Creek, near Middle Beach. These oysters grew rapidly to market size and were well received when sold. In 1979, a joint venture between ICI and the South Australian Department of Fisheries resulted in the development of a hatchery and growout facility at Dry Creek. The ICI/Cheetham Salt hatchery operated from 1979 to 1987 producing oysters marketed under the name of Gulf Oysters (Hone

1993). It is believed to have closed as a result of Cheetham Salts refocusing on its core business priorities (Hone 1993), although physical reconfiguration of the growout pond for improved salt production making environmental conditions suboptimal, affected the success of growout earlier (Wallace-Carter 1987).

- South Australia's only Western King Prawn (*Melicertus latisulcatus*) hatchery, nursery and extensive pond growout venture (the most expensive aquaculture development at the time), the Racavolis Prawn Culture Centre (or the Old Port Broughton Prawn Farm as it was also known), was established and operated during the 1970s at Port Broughton about 170 km north of Adelaide. Despite its success in capturing 'ripe' female and male prawns in the Spencer Gulf hatchery and producing larvae and then juveniles that were stocked to extensive ponds (Wallace-Carter 1987), the venture was thought to have failed because of growout issues, particularly lower than expected production levels due to the cooler temperate temperatures (most current prawn farming is done in the tropics and sub-tropics) and that as a burying species, the Western King Prawn can be challenging to harvest.
- Initial attempts to commercially produce the Blue Swimmer Crab (*Portunus pelagicus*) in South Australia were undertaken in 1996-97 at the small and rudimentary Yorke Regional Development Board Aquaculture Centre at Wallaroo and the prior Old Port Broughton Prawn Farm, and then in 1998-99 at the Spencer Gulf Aquaculture Facility, a finfish hatchery and pond, adjacent the power stations at Port Augusta. While small scale hatchery, nursery and very limited growout trials were successful, production was not able to be increased to achieve commercialisation as a result of water quality issues within the hatchery (Smallridge 2002).
- Two small Pacific Oyster leases that were in operation for a few years from about the mid to late 1990s on the western side of Spencer Gulf between Whyalla and Port Augusta (PIRSA 1998).
- A significant Pacific Oyster farming area in an intertidal aquaculture zone offshore of Port Broughton. This was occupied by Pacific Oyster leases during the 1990s and early 2000s, but with no production since (pers. comm. Xiaoxu Li, SARDI, 2017). It is believed that production stopped primarily because of suboptimal oyster growth and conditioning.
- Adjacent to the Port Augusta power stations, pond-based research of Western King Prawn growout occurred in the mid-1980s (SADF 1989), whiting growout (King George Whiting, *Sillaginodes punctatus*, and Yellowfin Whiting, *Sillago schomburgkii*) in the late 1980s (PIRSA 1998), and zooplankton culture for larval finfish feed in the late 1990s (PhD project, Department of Zoology, University of Adelaide). Pacific Oysters were also farmed for a short period in the

power station cooling water inlet channel but were detrimentally affected by rapid biofouling growth. Prawn production was unsuccessful because of pond design and resulting suboptimal water quality. Whiting culture demonstrated that Yellowfin Whiting grew more rapidly than King George Whiting, but neither were likely to be commercially viable at that time, and that the composition and abundance of the zooplankton species cultured were too erratic for commercial use as a larval feed because of the substantial seasonal and sometimes extreme diurnal pond water temperature fluctuations experienced.

- South Australia's first commercial finfish (Snapper and then Yellowtail Kingfish) hatchery, which operated at Port Augusta from about 1996-2010. Snapper were first propagated at SARDI at West Beach, Adelaide in about 1995 with field trials with regional development groups and interested commercial participants at Whyalla and Port Augusta in 1995 and 1996, respectively, using wild caught juvenile Snapper (Hutchinson et al. 1997). A small research and development (R&D) hatchery was also developed and operated at Whyalla for a short period. The hatchery at Port Augusta was successful in producing Snapper and Yellowtail Kingfish for commercial sea cage farms offshore of Cowell and at Fitzgerald Bay, to the north-west of Whyalla, but was closed after being taken over by a company with a larger and more centrally located (to their main operations) hatchery at Arno Bay. The hatchery at Port Augusta successfully addressed issues with the water source (salinity of 44-48 ppt and temperature >20°C all year-round water of the power station discharge channel), by diluting it with municipal reticulated freshwater and passing it through a charcoal filter to remove the chlorine/chloramines.
- Occasional, sporadic, small-scale harvesting of adult Brine Shrimp (*Artemia spp*) for frozen product for the aquarium trade from a seeded, shallow, hypersaline pond adjacent the power stations at Port Augusta (this also occurred from a southern pond associated with the Dry Creek Salt Fields just to the south of 2W2W).
- Onshore facilities, including maintenance, storage and processing, associated with commercial Snapper and then Yellowtail Kingfish sea cage farming in Fitzgerald Bay, to the north of Whyalla (Hutchinson et al. 1997). From about 2004, growout operations were consolidated and moved south after the two commercial farms in the area experienced high mortalities associated with a nutrient deficiency in the commercially supplied pelleted feed. Yellowtail Kingfish operations are planned to be reinstated in Fitzgerald Bay in late 2018-2019.
- Onshore facilities, including ponds and tanks using recirculated groundwater, for small scale Brine Shrimp production for the aquarium trade and development of finfish aquaculture (e.g.

trial with King George Whiting) in the early 2000s near Tickera, between Wallaroo and Port Broughton. It is unknown why the company undertaking these activities closed.

Just to the south of 2W2W, between 1990 and 2010, land-based aquaculture ventures were considered a number of times on Torrens Island (approximately 18 km north-west of Adelaide):

- The establishment of a commercial Mahi Mahi (*Coryphaena hippurus*) and then Snapper farm were explored by private investors on land adjacent the AGL Torrens Island Power Station, where they were seeking to capture the benefits of the heated cooling water discharge.
- A microalgal 'demonstration-scale' R&D operation on land just north of the Torrens Island Quarantine Station (Taylor 2010**Error! Hyperlink reference not valid.**).

These ventures did not eventuate, with the finfish ones experiencing regulatory and technical issues associated with connection to the desired input and output services required for their operation, and the microalgal one, because the private company involved became insolvent.

Despite the considerable land-based aquaculture R&D that has been undertaken, and the failure of many small start-ups, it is still seen as a sector with capacity for substantial growth, primarily because of its potential to use resources that are presently under-utilised to meet a global need for more seafood. The general strengths, weaknesses, opportunities and threats (SWOT) of the sector are highlighted in Table 2.1 (modified from Mussely and Goodwin 2012).

Table 2.1: Strength, weakness, opportunities and threats analysis for the potential of land-based aquaculture in the 2W2W (adapted from Mussely and Goodwin 2012).

Strengths	Weaknesses
• High production rate per hectare in more intensive systems • Ability to control growing conditions • Low water intake and discharge requirements of recirculation aquaculture systems • Good Feed Conversion Ratios • Higher level biosecurity feasible • Better control of discharges possible than with in-sea aquaculture • Improved security on private land • Potential for integrated farming systems that are eco-friendly • Feasibility of high quality science and research support • No spatial competition with ocean users • History of successful farming/animal husbandry	• Seasonal temperate Mediterranean climatic pattern resulting in suboptimal culture conditions for part of the year without technical intervention • Low rainfall and groundwater recharge, limited surface water and high evaporation, and a shallow coastline with species of conservation significance, limiting water access and/or availability • Limited knowledge of groundwater temperature, water quality and volumes • Small domestic market and considerable distance to major interstate and international markets • Lack of specialized knowledge of and demonstration state-of-the-art intensive recirculation and aquaponics systems • Lack of investment funds • Potential high energy cost of recirculation systems • No fish feed plant in SA, increasing the cost of feed • Much high-technology land-based aquaculture equipment needs to be imported from overseas, increasing costs
Opportunities	**Threats**
• To benefit from increasing domestic and global seafood consumption and interest in 'buying local' and 'clean and green' • To grow the aquaculture industry, increase exports and create regional employment • To make better use of the fresh, brackish and seawater resources available • To make better use of renewable energy resources to reduce energy costs • To establish intensive recirculation systems and aquaponics as significant commercial production systems in SA and nationally • To gain from the increasing market for eco-labelled products	• Freshwater may be limited to the 'left overs' after other users • Competition from similar developments and products in other regions of SA, national and internationally • Increased production depresses product market price • Biosecurity constraints inhibiting the use of non-endemic species • Perceived backlash against perceived industrially, high density production of seafood ('battery fish') • Intake and effluent regulations are too challenging to address in a cost effective and timely manner • Climate change predicted to further limit freshwater resources • Business risks associated with aligning aquaculture production with other, potentially larger, core business, industries

2.2. Land-based aquaculture systems

Aquaculture systems vary from intensive to semi-intensive and extensive, with these terms reflecting the typical stocking density of aquatic organisms that can be cultured within the system and level of system control applied. The characteristics of alternative land-based aquaculture production systems are presented in Table 2.2 (adapted from Gooley and Gavine 2003).

Table 2.2: Summary of characteristics of alternative land-based aquaculture production systems (adapted from Gooley and Gavine 2003).

	Stocking density	Advantages	Disadvantages
Farm dams	Low: <500 fish ha^{-1}	• Low cost as already constructed for water storage • Low maintenance	• Minimal control over ambient environmental conditions and predators • Can be challenging to harvest from • Low yield
Ponds	Moderate-High Flow through: > 30 kg m^{-2} Static: 4-5,000 fish ha^{-1}	• Relatively cost-effective, especially if gravity fed and drained • Optimises ambient growing conditions • Minimises stock losses through escape or predation	• Moderate-high land requirement and construction costs • Little control over ambient environmental conditions • Stock management may be difficult • May have high water consumption
Cages in water bodies	Moderate: 15-25 kg m^{-3}	• Use of existing waterbodies • Technical simplicity and easy establishment and expansion • Lower capital cost compared with land-based farms • Easier stock management and monitoring	• Little control over ambient environmental conditions • Stock may still be vulnerable to predators (less than in ponds)
Tanks (flow-through)	Moderate: 20-30 kg m^{-3}	• Less maintenance and training required for operation • Relatively inexpensive set-up costs compared to RAS	• Higher water use than recirculation and static ponds • Little control over water temperature (but some protection from the elements)

		• Can use existing shedding or buildings • Easier to observe and harvest stock • Easier to prevent stock escape and predation	• Stock vulnerable to external water quality
Recirculation Aquaculture Systems (RAS)	High: >50-100 kg m^{-3} (depending on whether aerated or oxygenated)	• All production variables can be controlled to achieve optimum fish performance • Low water consumption per unit weight of fish produced • Impact on external environment minimized by small footprint and low level of wastewater • Year-round production • Secure and biosecure	• High capital cost ($0.25-0.5 million in 2002 for a 20 tonnes $annum^{-1}$ system) • High operational costs ($7-10 kg^{-1}) • High level of skill and management and constant maintenance required

2.2.1. Extensive aquaculture systems

Extensive land-based aquaculture systems are characterised by water bodies with low stocking rates and production levels at coastal, estuarine or inland sites that have been modified by human intervention to typically maintain water levels and/or control water exchange to only a minor degree so as to create or isolate the water body. The level of intervention is low (e.g. a dam wall to retain water) with new water entering perhaps through a screened pipe as part of a natural tidal cycle or from rainfall, and with feeding of the aquatic organisms occurring through the natural food chain or by provision of only a very low level of supplementary feed. In such instances, the environment of these water bodies is typically close to natural and aquatic organism densities are low, often less than a few tonnes ha^{-1} of water surface area.

Large extensive land-based aquaculture systems are not common in southern Australia, but examples include the culture of Yabbies' (e.g. farm dams) and Eels (e.g. netted lake areas), primarily in higher rainfall areas. In South Australia, a state characterised by generally low rainfall, Yabbie farming is generally undertaken in shallow ponds (often little more than bulldozed depressions in the ground) and farm dams, with the Yabbies reliant on rainwater and the presence of natural feeds.

The advantages of extensive aquaculture systems are their typically low capital and operational costs as they tend to rely on the natural topography and resources at the site; and the lower-level risks and management required because of the low stocking densities, lack of equipment that can malfunction and largely natural environment. Their disadvantages are their lack of environmental control, including the difficulty in managing biosecurity and the potential for stock losses from predation and poaching; harvesting of stock for market; low quantity (typically less than 1 tonnes ha^{-1}) and consistency of the product produced; and their large environmental footprint.

In many parts of South Australia, including 2W2W, the low rainfall and high evaporation rates are a challenge for extensive freshwater aquaculture and most such systems comprise only a small number of small water bodies. For example, if their total surface area was one hectare and they experience an average annual rainfall and evaporation rate of 400 mm and 2000 mm per annum, respectively, it will require an additional 16,000 KL $annum^{-1}$ of water just to maintain the water level, disregarding any other losses that might occur such as through seepage. Deeper water bodies, particularly gully dams, also take longer to warm, reducing the growth of warm temperate species within them. They also have the potential to stratify in summer due to the establishment of a thermocline (warm oxygenated water above and cold deoxygenated water below). When the thermocline is disrupted, often through wind generated water circulation, the lower oxygen deficient water can rise and mix throughout the water body causing asphyxiation of the aquatic organisms present.

2.2.2. Semi-intensive aquaculture systems

Semi-intensive aquaculture systems typically comprise specialised culture ponds, raceways and tank systems that enable a moderate stocking rate and production level. They are designed specifically to increase production through greater control of the culture environment, such as greater flow rates to maintain water quality, aeration of the water, control of predators and well managed feeding. However, as these systems are typically outdoors, they are largely uncontrolled in relation to culture temperature and biosecurity.

Semi-intensive pond, tank and raceway aquaculture in southern Australia is typically used for the production of Marron, Murray Cod, Silver Perch, Golden Perch, Salmon and Trout. The stocking densities in fishponds and outdoor raceways vary considerably, but most are within the range of 5-15 kg m^{-3}.

Examples of semi-intensive aquaculture in South Australia are Marron farms and most of the small number of native finfish farms, which are all typically in the wetter areas of the state (e.g. Fleurieu Peninsula and Kangaroo Island).

The advantages of semi-intensive aquaculture systems are their higher production capability through higher stocking rates and greater management control; and their moderate capital and operational costs (e.g. specially constructed ponds have a 'plastic' lined bottom that prevents water loss to the underlying water table and often havecapacity to add, remove or transfer water between ponds providing greater control over management of systems and reducing operational costs). The disadvantages of semi-intensive systems are primarily their need to pump and often aerate the water used for holding the farmed species, intake and water discharge quantities; and moderate production level and environmental footprint. These systems are typically sited outdoors, with limited capacity for environmental control, biosecurity, and protection of stock from predation and poaching.

Similar to extensive freshwater aquaculture ponds, low rainfall and high evaporation rates are also a challenge for semi-intensive freshwater aquaculture. A reasonable size, semi-intensive pond based native freshwater finfish farm (e.g. Silver Perch) in southern Queensland or New South Wales typically comprises 5-10 ha of ponds of 0.7-2.5 m deep, producing about 50 tonnes of finfish annually. The ponds are likely to be 'plastic' lined on the bottom, aerated with paddlewheels, have some exchange of water to manage water quality, and be drained annually to harvest the final fish and dry and 'sterilise' the pond. For 10 ha of such ponds in a typical area within 2W2W, one can estimate that some 200,000 KL of water would be required to fill the ponds annually, assuming: an average depth of 2 m; 160,000 KL of water would be required to replace the water lost to evaporation assuming 400 mm and 2000 mm per annum of rainfall and evaporation, respectively; and 20,000 KL per annum would be required for water exchange for management purposes assuming that 10% of the volume of the ponds was required for this purpose.

Sourcing this 380,000 KL annually would require a groundwater bore with a flow rate of approximately 12 L s^{-1}. This is feasible within 2W2W but involves the pumping of a substantial quantity of water for a system without the capacity to achieve optimal temperatures for the growth of the cultured species for much of the year and one which is well below a size that achieves any significant economy of scale.

2.2.3. Intensive recirculation aquaculture systems

Intensive RAS technology has steadily developed over the past 30 years, and is now used for broodstock management, in hatcheries and nurseries, particularly for salmon smolt production. By comparison, the progress of RAS for the growout of fish species to market size has been much more restricted and there have been many failures (e.g. Bostock and Fletcher 2014). There are, however, a range of species now being farmed in RAS, although primarily salmon in countries such as Canada, China, Denmark, United Arab Emirates (UAE), United Kingdom (UK) and USA.

RAS are characterised by their high stocking and production level; controlled indoor environment; multiple reuse of water with the internal water passed through treatment processes to remove wastes and maintain appropriate water quality; and small environmental footprint. RAS have a relatively low need for incoming water and wastewater discharge (typically less than 10% per day), reusing the majority of water within the system as it is circulated on an ongoing basis where it is processed to maintain water quality. RAS are generally fully temperature controlled to optimise the production of the farmed species and have the capacity to provide a highly biosecure environment (e.g. Bregnballe 2015).

Generic RAS components typically include one or more pumps, biofilters, solids collection system (e.g. a backwashing screen filter), foam fractionation unit (often referred to as a protein skimmer), carbon dioxide degasser, nitrate filter, sterilisation points (e.g. UV sterilisation), tank drainage system that separates waste from main outflows, water and often water temperature control (e.g. heat pump or evaporative cooling), heat exchange of effluent waters, air or oxygen injection system, and a pH control and alkalinity dosing system (e.g. Hutchinson et al. 2004, Pentair 2016). Often several of these components are combined for simplicity and capital savings, but this can compromise the reliability of the total system. Also, while there are many ways to build a RAS, no one way is said to be best across all species, budgets and situations.

RAS typically have stocking densities of 30-100 kg m^{-3}, but with Eels, occasionally as high as 200 kg m^{-3}. Species that have been grown in this type of system in southern Australia, primarily in Victoria, include Eels, Barramundi, Brown and Rainbow Trout, Golden Perch, Silver Perch and Murray Cod. In South Australia in the early 1990s, a Silver Perch RAS operated in the Adelaide Hills, but it was unprofitable because the system used natural water temperatures which were too cold for good Silver Perch growth except during the summer period. South Australia has also had from the mid-1990s, small (about 20 tonnes $annum^{-1}$) RAS, originally designed and installed by the company Fish Protech, producing primarily Barramundi and Jade Perch. Most of the larger ventures have now closed, primarily because they were too small to be profitable, and production was occasionally impacted by system malfunctions and fish disease. However, there are still several small-scale RAS in operation by aquaculturists in South Australia; one at St Kilda north of Adelaide in the southern NAP region, and another at One Tree Hill in the northern Adelaide Hills. A small, native fish venture (e.g. Barramundi, Eels and Murray Cod) operating on captured and stored rainwater, exists at Whyalla, but only produces seasonally as it does not include a system to maintain water temperatures at a level adequate for growth of the species farmed in winter. The only saltwater RAS in South Australia is near Beachport in the south-east of the state producing Ocean Trout.

The advantages of RAS are their high production capacity due to high stocking rates; the excellent feed conversion efficiencies achievable through managed feeding, small physical footprint on the land; low level of water intake and discharge; potential for high biosecurity control; potential to produce organically certified product with a higher market price; low labour requirements; capacity to concentrate wastes that if from a freshwater system can readily be used as a horticulture or agriculture fertiliser; capacity for integration with other land-use activities; and much higher potential to be sited near the market for their product (e.g. in outer urban, commercial and industrial areas). Their disadvantages are their high capital cost; high system operating costs; potential for their product to be different and considered inferior due to off-flavours and/or fattier fish; a general inability to increase production greater than that achieved at start-up if market prices of the farmed species decline; the challenges of modifying and optimising the system if another species were to be farmed (depends on the species); and the high business risks of running a highly stocked system dependent on a wide range of equipment that must operate within close tolerances (e.g. system failures like a disease outbreak can be catastrophic).

RAS are specifically designed to match the biological and environmental requirements of the species cultured and the harvest strategy to be used to supply the market (e.g. weekly or monthly harvests). A RAS, comprising only facilities for ongrowing of fry and then fingerlings to plate-size, to produce about 140 tonnes annum^{-1} of an easily cultured species (e.g. Tilapia in the USA), would have a main building of about 1,000-1,200 m^2 in area. his would house tanks with a capacity of about 600 m^3 and based on a daily exchange rate of about 5-10% of the water volume of the facility, take in and discharge about 0.7 L s^{-1} of water to maintain appropriate water quality. A higher flow rate would be desirable for more rapidly filling tanks after cleaning and/or emptying. For on-site fish feed storage, discharge water treatment (e.g. belt filter for further dewatering, effluent receiving and storage ponds and possibly geotextile bags on gravel beds for further water processing and dewatering and spray irrigation), vehicle parking and an office and product packing area, one - two hectare of land would be desirable (Pentair 2016).

For comparison, a 1,000 and 3,000 tonnes annum^{-1} Atlantic Salmon production RAS with a maximum growout density of 75 kg m^{-3} would have, respectively, a total tank (hatchery, smolt and growout) capacity of 11,842 and 36,036 m^3, an intake and discharge water flow rate of 31 and 83 L s^{-1} (about 1.4/9 L s^{-1} of freshwater and 29.5/93 L s^{-1} of seawater), and a feed rate of about 2.8 and 8.4 tonnes day^{-1} (Billund Aquaculture 2016). The footprint of such a RAS building can vary considerably depending on species and tank volume but is typically about 2-4 m^2 kg^{-1} $annum^{-1}$ of fish produced, with at least double this desirable for the whole site (pers. comm. Patrick Tigges 2017, Billund Australia). Based on this and on-line data on a number of European intensive RAS, a 1,000/3,000 tonnes $annum^{-1}$ RAS would typically require a maximum site area of 4,000/12,000 m^2.

To achieve economies of scale, RAS have moved from 20-50 tonnes $annum^{-1}$ production units in the 1990s, to 1,000-3,000 tonnes $annum^{-1}$ production units in the 2010s, with 10,000 tonnes $annum^{-1}$ and larger production units now being planned (Billund Aquaculture 2017).

The well publicised failure of many past RAS operations in the United Kingdom, Europe, USA and elsewhere, has been primarily associated with the lack of readily available expertise on their installation and use (Badiola et al. 2012). In Australia, the incomplete biological data for many native aquatic species considered to have aquaculture potential and the rarity of operating RAS, has further discouraged a move to such systems. However, there is increasing recognition of their commercial potential based on considerable improvements in system design over the last decade, increased knowledge of their use with a small group of select species, and a recognition that economies of scale must be incorporated for commercial success (e.g. Bostock and Fletcher 2014, DNB 2017).

A cautious but positive approach to the adoption of RAS technology for growout is advocated by Bregnballe (2015), whereas DNB (2017) and Billund (pers. comm. Patrick Tigges, Billund Aquaculture 2017) believe that prospects have currently never looked better for appropriate RAS developments because of system advances over the last few years and the current positive economic environment for fish farming in certain countries.

2.2.4. Integrated aquaculture systems

There has long been great interest in the capacity of integrated aquaculture systems to be more sustainable and environmentally friendly, and polyculture has been practiced in places such as Asia for thousands of years. However, the practice of integrated aquaculture is relatively new in western countries, and what is occurring is generally either at R&D, demonstration or small commercial scales. This is, however, changing rapidly in some countries, where a number of different types of integrated aquaculture systems now exist.

Polyculture

Polyculture is the farming of multiple species together, often in the same water body but sometimes in parallel interconnected water bodies. It has been undertaken in ponds for thousands of years in Asia, typically based on the farming of surface, mid-water and bottom feeding aquatic organisms in the one water body to more effectively utilise the naturally available feeds.

Polyculture is rare in Australia, largely because of a lack of availability of suitable freshwater aquaculture species of different trophic level to grow in combination and aquaculturists experience and/or perception that the farming of a single species is sufficiently challenging.

Integrated Multi-trophic Aquaculture

Integrated multi-trophic aquaculture (IMTA) is a form of polyculture, where different trophic level aquatic species are farmed in close association to maximise the utilisation of the resources available. For example, the wastewater from prawn ponds may be directed to a water body holding filter feeding molluscs that consume organic particulate matter and then to another water body holding macroalgae that assimilate dissolved nutrients.

While commercial examples exist overseas, none exist in Australia, with early investigations associated with the development of IMTA in Australia associated with marine finfish farm areas (Atlantic Salmon in Tasmania and Southern Bluefin Tuna in South Australia).

Integrated Aquaculture Biosystems

Integrated aquaculture biosystems are typically systems that align aquaculture and intensive terrestrial animal husbandry industries (e.g. dairy, pork and poultry) to convert high nutrient wastewater produced during the farming of the terrestrial animals, to a saleable aquaculture product (e.g. Kumar 2000). The bioconversion of solid animal farm wastes may also be used to provide an energy supply to the terrestrial animal and aquaculture operations.

Aquaponics

Aquaponics is the integration of hydroponics (an intensive, resource efficient and productive terrestrial plant growing system that doesn’t use soil) with RAS to enable the waste nutrients from production of finfish to be used to support the growing of crops (e.g. herbs, fruit and vegetables; Dudley 2017). Other benefits can also be achieved through synergies associated with the use of labour; conservation of power;

buildings and transport of perishable products; using the volume of water in both systems to conserve and store heat, which can enhance production of the farmed species; and using the concentrated wastes form the RAS to produce fertiliser that can be used for horticulture. Carbon dioxide production from the fish system can also be used to stimulate crop growth. Within aquaponics the use of synthetic chemicals are largely eliminated and many operations target the production of higher value, organically certified products. Information provided in Table 2.3 (adapted from de Dezsery 2010 and pers. comm. Andrew de Dezsery, Aquaculture Advantage, 2016) summarises the general strengths, weaknesses, opportunities and threats (SWOT) of aquaponics.

Many alternative aquaponic systems are used (Love et al. 2015a), with the most common being raft (deep water culture) aquaponics, in which water from the fish tanks flows into a series of solid filtration and biofilter tanks, that respectively serve to remove large solids and use bacteria to breakdown ammonia into nitrate. From these tanks water flows through the crop/plant beds, where polystyrene or other materials are used for buoyancy to float crops planted inside net-pots which are inserted in holes in the floating rafts in tanks of water about 0.2-0.4 m deep, before returning to the fish tanks. Media beds contain soil-less media, such as expanded shale or clay pebbles and are used to grow crops with a flood-and-drain irrigation method. Wicking beds are similar to media beds, however, wicking beds are filled with absorptive growing media such as coconut coir. In the nutrient film technique, a fine mist of water is sprayed or dripped onto plant roots in a horizontal gutter or tray design. Vertical towers are similar to the nutrient film technique, except crops are instead grown in a vertical tray or tube. Dutch buckets are irrigated container planters filled with soilless media. With all aquaponics systems, a stable ecological system and maximum crop and fish production is achieved by controlling such factors as water temperature, pH, micro- and macro-nutrients, dissolved oxygen and light intensity and photoperiod.

Love et al. (2015a) undertook a survey of commercial-scale aquaponics enterprises and documented the production methods, crop and fish yields, and profitability. The on-line survey collected data from 257 respondents with 81% in the USA and the remainder from 22 other countries, including 12 (5%) in Australia. Overall, greenhouses were the most popular facility for housing aquaponics either in combination with another facility (41%) or exclusively (31%). Aquaponic systems were primarily self-designed (71%), with the majority of hydroponics undertaken using a combination of two or more methods (69%), with the most common commercial approach being to use rafts and media beds together (26%). The popularity of the specific methodologies were: floating rafts (77%), media beds (76%), nutrient film technique (29%), vertical towers (29%), wicking beds (9.5%) and Dutch buckets (5%). The average commercial production size was 0.01 ha and 10,300 L in volume, employing 1-2 full time workers and one part-time worker. The average respondent grew two species of aquatic animals, with Tilapia (Barramundi, Jade Perch and Silver Perch in Australia) and ornamental fish the most common and with a median fish production 23-45 kg annum^{-1}. The most frequently raised plants were basil, salad greens, non-basil herbs, tomatoes, lettuce, kale, chard, bok choi, peppers and cucumbers, with the median quantity of plants harvested 45-226 kg annum^{-1}. Production was skewed towards plants as compared to fish, for economic and biological reasons, which included the higher price of some herbs and salad greens than fish; the fact that crops reached marketable size sooner; and biomass conversion ratio for crops is better than fish. For example, as much as 9 kg of lettuce can be produced using fish manure from 1 kg of fish feed, whereas FCR for fish are closer to 1:1. Aquaponics was the primary source of income for only 30% of those surveyed with 37% of operators generating less than about US$50,000 annum^{-1} gross revenue (median US$1,000-5,000) and 31% indicating a profitable operation in the last 12 months and 55% expecting to be profitable in the next 12 months. The point at which most of those surveyed indicated profitability was >US$50,000.

Love et al. (2015b) described the operating conditions, inputs (energy, water and fish feed) and outputs (edible crops and fish) and their relationships over two years for a small-scale (10.3 m^3, US$5,000 annum^{-1} in sales) raft aquaponics operation in Baltimore, Maryland, USA. While not representative of a modern larger scale commercial system, it did provide some interesting quantitative data. The system roughly had a 1% water loss day^{-1}, using an average of 35.9 KL for replenishment annum^{-1}. Energy use was 19,526 kWh, with in-tank heaters the main energy users. Comparing inputs to outputs, 104 L of water, 0.5 kg of feed and 56 kWh were needed to produce 1 kg of crops, and 292 L of water, 1.3 kg of feed and 159 kWh of energy were needed to produce 1 kg of Tilapia. The authors determined that an understanding of energy, water and feed use in aquaponics systems was fundamental to inform farm business development and operational plans.

Table 2.3: Strengths, weaknesses, opportunities and threats analysis for aquaponics systems (adapted from de Dezsery 2010 and pers. comm. Andrew de Dezsery, Aquaculture Advantage, 2016).

Strengths	Weaknesses
• Production of multiple agri-products from single input nutrient source through waste-stream value adding • Efficient use and portioning of nutrient resources enabling total nutrient resource conservation • Diversity of species grown and products produced using a single re-circulated water resource on a single footprint • Water sustainability through waste re-use in closed hydraulic systems • Establishment of nature-mimicking systems with all the added benefits of complex ecologies equating to improved pollination, lowered occurrence of diseases and pests, etc • Ability to produce higher biomass per unit area of fresh food and do this in enclosed buildings in urban areas where food is consumed reducing transport costs and carbon footprint • Merging of existing intensive horticulture and aquaculture farming practices to create new markets and employment • Aligns with Australia's innovative, clean, green and health image	• Environmental disasters (e.g. storm induced power outages and damage to greenhouses) • Lack of human resources with the vision and required knowledge and practical experience • Challenge of obtaining reasonably priced, certified organic fish feeds • Lack of public awareness and take up of the benefits of environmentally sustainably produced foods and organic certified products • Distance to some markets if large operations are established to achieve economies of scale • Potential for product oversupply with growth of aquaponics resulting in price reductions and seasonal competition from traditional monoculture produced products produced in large quantities

Opportunities	Threats
• Increased use of urban locations for production aligned with move to higher living densities • Public perception and interest in chemical spray-free food production • 'Greening' of urban environments through food production allows the dual advantage of food and passive environmental enhancement • Global markets are currently under supplied in high-grade and chemical-free foods • Adoption of simplified, low-technology systems by removing the technological complexity • Lower waste by recycling and end-waste product utilisation • Water re-use for zero waste • Local and regional employment • Increased market penetration • New technology development • Improved husbandry practices for animals minimizing diseases and pests	• Diseases and pests • Ignorance of sustainability and organic certification agencies to appropriately address aquatic production systems • Industry failures, often due to seeking to develop too quickly or poor advice, which negatively impacts on the perception of the industry • Lack of application and continued development of world best practice • Government policy and legislation not in step with aquaponics developments • Consumer acceptance of alternative, less fresh and often more processed cheaper products

2.2.5. Inland saline aquaculture

Large areas of land in Australia and other countries has groundwater beneath it where salinities are too high for use for potable drinking, agriculture use and watering of stock. The use of this saline water for aquaculture has long been considered to have economic potential (Allan et al. 2011a, 2011b) and much research and a number of proof-of-concept feasibility studies have been undertaken in Australia. These include studies by Partridge et al. (2006, 2008) in Western Australia (WA), Hutchinson and Flowers (2008) in South Australia, Gooley and Gavine (2003) in Victoria, Fielder et al. (2001) and Doroudi et al. (2006) in New South Wales and Partridge et al. (2008) in Queensland.

A wide range of systems and species have been investigated for inland saline aquaculture, including, extensive, semi-intensive and RAS, and algae, crustaceans and finfish. However, despite some promising results no significant industry has yet developed, even for species that are aquacultured commercially elsewhere. Interest continues in this field and ongoing R&D is building the knowledge base required to address the issues identified. This includes the environmental tolerances and optima of species, especially to the variable ionic nature of groundwater; more cost-effective aquaculture system designs that enable an optimal environment to be provided for the species cultured; and improved and cost-effective methodologies for treating water prior to and after use.

2.2.6. Shore-based marine aquaculture support services

The Eastern Spencer Gulf Aquaculture Zone (PIRSA 2017c), which includes Tickera subtidal and intertidal zone, Wallaroo subtidal zone, and the Port Broughton intertidal zone; and the Fitzgerald Bay Aquaculture Zone just north of Whyalla, western upper Spencer Gulf; are offshore of 2W2W and have the capacity to support further in-sea aquaculture development. Such growth will likely require supporting infrastructure on land, including that for servicing offshore structures and equipment; feed storage, and possibly production and manufacture; and seafood product processing, distribution and storage. Other services that may require land-based regional support include infrastructure assembly and/or manufacturing, R&D, education and training, and veterinary support.

3. Species Selection

A successful long-term, economically viable, commercial aquaculture enterprise is dependent to a high degree on the selection of an appropriate culture species, in addition to a suitable site and farming system. Achieving this is often challenging and as such a wide range of techniques have been developed to facilitate the process, varying greatly in the number and extent of parameters they investigate.

Quemener et al. (2002), in seeking a prioritised list of new candidate species for aquaculture for a substantial geographic region of Europe, considered four general parameter groupings that comprised production, transformation (yield), distribution and consumption, and a ranking of 32 criteria across these groups, with the key criteria being:

- aquaculture potential (based on the amount of information published on the species and how easy it would be to obtain juveniles or broodstock);
- adaptation potential to the environment (based on species known distribution and temperature optima/tolerances);
- growing out potential (annual weight increase to market size);
- rearing potential (time to market size);
- transformation potential (yield following processing);
- practical use potential (boniness);
- consumer image (how well the fish is received by present consumers);
- consumption (potential different product types); and
- flesh quality (e.g. nutritional status, colour, taste).

Stage 1 of the prioritstion involved an assessment of 20,000 marine species, which at subsequent stages was reduced to 8,063, then 71 and finally 32 species.

More recently, Alvarez-Lajonchere and Ibarra-Castro (2013) considered 50 species identified as already of commercial importance to fisheries and/or aquaculture, and therefore to already have some demonstrated level of economic viability. They also undertook a staged approach to assessing many 'weighted' criteria for each species with the key ones being:

- state of development of culture technologies;
- market potential;
- level of captive maturation and spawning control;

- level of development of juvenile mass production technology;
- growth rate of juvenile during the nursery stage;
- time to growth from juvenile to commercial size;
- biomass yield;
- juvenile yield;
- feeds and feeding;
- environmental tolerances; and
- extent of economic information available.

Alternatively, many Australian State Government aquaculture guides (e.g. NSW Government 2009) recommend a relatively simple decision-making system to assess which species to culture, including:

- is the species permitted for your location and farming method?
- is there a ready supply of juvenile stock or will they have to be produced as part of the aquaculture venture?
- market analysis (e.g. acceptability of product at a price that ensures a viable business).
- the biological feasibility of culturing the species (e.g. environmental tolerances and optima for growth and survival, degree of control over the life cycle, growth rate, feed availability, food conversion efficiency, stocking levels achievable, susceptibility to stress and disease).

Many aquaculture start-up guidelines also highlight that selecting a species that is already commercially cultured has advantages due to less business risk as much more will be known about the species; it is easier to capture a share of an existing market than develop a new one; and time from start-up to production is likely to be much shorter. They and others (e.g. Alvarez-Lajonchere and Ibarra-Castro 2013) also advocate a cautious approach involving preliminary screening, R&D if required, a pilot study, and then, if possible, a staged approach to commercial development, so that the business is grown over time.

Here, emphasis has been placed on identifying aquaculture opportunities that can be developed within a relatively short time frame, rather than over many years. As such, more weight has been put on selecting species and farm systems that are already resulting in commercial production, either in South Australia or nationally or that business investors have already registered an interest in commercialising.

3.1. Market analysis

A key criterion across most aquaculture species selection frameworks is market price and demand (Le Francois et al. 2002). This includes ensuring that there is a market for the species in question, as well as access to this market. It may also include consideration of the product yield (how much can be recovered following processing), form (fresh, chilled or smoked, etc.) and quality (e.g. human nutritional characteristics, including beneficial omega-3 fat levels). Consumer acceptance is also a key consideration, as there is no market without consumers (Thouard et al. 1990) and consumers are often sensitive to the boniness, flavour, colour and texture of the product. In regions where there is wild-catch of the species, it can be important to consider competition between this product and that produced from aquaculture, recognising that many wild-catch species has a distinct seasonality to their availability (i.e. typically a function of fisheries management policies and/or catchability).

The benefit of many past marketing studies undertaken in South Australia targeted at identifying and prioritising aquaculture species most suitable for development have often been questionable, because of the limited statistics readily available and the often-uncertain relevance of some of these. As such, the market analysis undertaken is this study has been used only as a first-cut approach to separate species worth considering further from an aquaculture perspective from those warranting less attention. This has been achieved by a review of:

- the ABARES fisheries and aquaculture statistics to determine the price per kilogram for the Australian fisheries and aquaculture taxa reported.
- the average annual sales figures from the SAFCOL Central Fish Market, Adelaide to appreciate the wholesale price and volume of sales.
- under-counter retail sale prices from the fish section, IGA Pasadena Supermarket, Adelaide, to better understand the relationship between different fish processing levels for a range of popular local species.
- live fish sales from Mark Lee Fish Farm, St Kilda, Adelaide, to obtain sales figures on a number of species of potential interest not sold by others in South Australia and also live product.

It is also worth noting that while no accurate estimate of seafood consumption exists for South Australia, an approximation of 7,700 tonnes annum^{-1} can be deduced from knowing that 1,676,653 people lived in the state at the time of the 2016 census (Australian Bureau of Statistics 2016) and that the Australian apparent consumption of seafood was 14 kg person^{-1} of which 67% was imported in 2014-15 (Savage

2016). It is also interesting that 2,000-2,500 tonnes of this might be Atlantic Salmon aquacultured in Tasmania (pers. comm. a Tasmanian salmon farming representative, 2017).

3.1.1. Australian Bureau of Agricultural and Resource Economics (ABARES) data

The 2017 ABARES fisheries and aquaculture statistics (ABARES 2018) provide an up-to-date overview of the farmgate value and weight of aquatic species harvested and sold domestically on a national and state basis. However, the data (Table 3.1) have many limitations as a market analysis tool as these only provide information for a relatively small number of 'species' defined by a generic marketing name, with some marketing names within a state comprising multiple species. Between states, the same marketing name may also comprise different species. The number of marketing names for aquaculture product are particularly low because the organisations collecting such data generally have agreements in place not to provide data that can identify the success, or otherwise, of any single business; a potential likelihood if only a few aquaculture ventures exist for a particular species.

Information in Table 3.1 highlights the species of higher (dark and light green), moderate (yellow) and lower value (light and dark red). The most valuable wild-caught species are Rock Lobster ($62.98-85.65 kg^{-1}), Abalone ($28.35-41.03 kg^{-1}), Coral Trout ($32.73 kg^{-1}), King George Whiting ($16.74-21.93 kg^{-1}) and Banded Morwong ($21.48 kg^{-1}); and aquaculture species, Abalone ($32.20-34.13 kg^{-1}), Marron ($30.65 kg^{-1}), Yabbies ($22.53-25.41 kg^{-1}) and Southern Bluefin Tuna ($15.52 kg^{-1}). Mid-priced wild-caught species include Western Australian Dhufish ($14.52 kg^{-1}), Eel ($14.09 kg^{-1}), Sand Whiting ($13.92 kg^{-1}), Wrasse ($13.57 kg^{-1}), Golden Perch ($13.50 kg^{-1}), Striped Trumpeter ($13.10 kg^{-1}), Prawns ($12.21-12.53 kg^{-1}), Squid ($10.52-15.55 kg^{-1}), Crabs ($7.23-15.04 kg^{-1}), Black Bream ($6.12-11.03 kg^{-1}), Barramundi ($10.76 kg^{-1}) and Snapper ($7.63-10.50 kg^{-1}). It is interesting to note most of these mid-value wild-caught species have also been the attention of aquaculture R&D, although only a few have been commercialized; these being Barramundi ($9.38-15.18 kg^{-1}), the salmonids - trout, Ocean Trout and Atlantic Salmon ($6.53-13.15 kg^{-1}) and Silver Perch ($9.51-12.24 kg^{-1}). This indicates that commercial success is not only dependent on market price, which is reinforced by the long-term profitable aquaculture of lower priced species such as Blue Mussels ($1.95-4.31 kg^{-1}).

The data also suggest that the value of some species differs between states, which may reflect the nature of the product produced, competition between aquaculture and wild-caught product at the market, or the nature of the market supplied (e.g. regional versus capital city, and supermarkets versus restaurants).

Table 3.1: Australian Bureau of Agricultural and Resource Economics (ABARES) data on fisheries and aquaculture production whole weight (tonnes) and farmgate value ($) for taxa for each Australian State for 2014-15 (does not include the Northern Territory). Dark green >$20 kg^{-1}, light green $15-20 kg^{-1}, yellow $10-15 kg^{-1}, light red $5-10 kg^{-1} and dark red <$5 kg^{-1} (adapted from Modsby and Koduah 2017).

		South Australia		Victoria		New South Wales		Western Australia		Tasmania		Queensland	
Wild-caught (WC) or Aqua-culture (A)	**Taxa** (can include a number of species or be different species in different States)	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})
WC	King Prawn	2,097	16.96		-	600	20.57					2634	12.80
WC	Banana Prawn											712	8.19
WC	Endeavour Prawn											541	7.19
WC	Tiger Prawn											1103	15.30
WC	Prawns			156	12.21	23	13.52	2979	12.53				
WC	School Prawn					683	9.80						
WC	Southern Rock Lobster	1,563	79.79	289	84.07	154	74.22			1040	85.65		
WC	Western Rock Lobster							6127	62.98				
WC	Rock Lobster & Morton Bay Bug											753	23.59
WC	Crab	668	7.23	7	12.14	507	15.04	705	10.09			2862	10.30
WC	Giant Crab									21	59.71		
WC	Abalone	745	33.88	739	27.33	124	28.35	248	35.84	1897	41.03		
WC	Pipi	430	7.12			111	9.98						
WC	Scallop							438	7.09	485	1.96	2041	2.16
WC	Cuttlefish					72	4.74						
WC	Squid	462	10.52	59	12.58	38	15.55					122	4.98

WC or A	Taxa	South Australia		Victoria		New South Wales		Western Australia		Tasmania		Queensland	
		Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})
WC	Octopus			21	4.10	202	6.35			81	9.72		
WC	Tuna							1	7.00				
WC	Australian Salmon	276	1.68	211	0.67	764	1.57	191	0.49	44	7.27		
WC	Mullet	138	5.14			2539	3.15					1937	2.50
WC	Sea Mullet							204	2.41				
	Yelloweye Mullet							20	1.30				
WC	Silver Trevally					84	5.37						
WC	Yellowtail Kingfish					113	9.45						
WC	Australian Herring	116	3.50					66	2.45				
WC	Shark			41	5.49			1035	3.55	11	9.45	573	3.00
WC	Snapper	586	8.64	147	9.42	164	10.50	357	7.63			60	8.12
WC	Tropical Snapper							1619	7.98			240	5.67
WC	Grey Morwong					21	4.43						
WC	Banded Morwong									44	21.48		
WC	Jackass Morwong									1	2.00		
WC	Mulloway					73	9.36						
WC	Luderick					375	1.72						
WC	Whiting							201	6.76			904	3.42
WC	King George Whiting	310	16.74	115	21.93								
WC	Sand Whiting					118	13.92						

WC or A	Taxa	South Australia		Victoria		New South Wales		Western Australia		Tasmania		Queensland	
		Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})
WC	Eastern School Whiting					768	3.40			3	7.33		
WC	Dusky Flathead					137	9.53						
WC	Bream (Black & Yellow) & Tarwine (QLD)			66	10.91	319	11.03	86	6.12			133	8.02
WC	Garfish	216	8.19	34	7.41					33	8.79		
WC	Leather-jacket	76	2.57										
WC	Australian Sardine	36,020	0.60	863	1.78			1763	0.86				
WC	Yellowfin Whiting	96	9.22										
WC	Estuary Cobbler							53	4.81				
WC	WA Dhufish							61	14.52				
WC	Spanish Mackerel							299	8.21			535	7.00
WC	Grey Mackerel											766	5.55
WC	Coral Trout											753	32.73
WC	Emperor & Redthroat Emperor (QLD)							431	5.13			202	6.73
WC	Blue Threadfin											157	4.00
WC	King Threadfin											345	4.35
WC	Rock Cod							359	7.62	2	4.50		
WC	Snook	45	4.60										
WC	Elephantfish									1	2.00		

WC or A	Taxa	South Australia		Victoria		New South Wales		Western Australia		Tasmania		Queensland	
		Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})
WC	Bastard Trumpeter									7	8.71		
WC	Striped Trumpeter									10	13.10		
WC	Wrasse									83	13.57		
WC	Barramundi											693	10.76
WC	Eel			66	14.09								
WC	Golden Perch	84	13.50										
A	Prawns					331	15.44					4951	16.40
A	Marron & Yabby	13	34.62										
A	Yabbie			3	5.33	15	22.53	17	25.41				
A	Marron							51	30.65				
A	Redclaw											45	23.18
A	Oyster	3891	7.30			3713	10.95			3266	7.00		
A	Southern Bluefin Tuna	8418	15.52										
A	Salmonids (mainly trout)			1147	6.53	277	10.25						
A	Salmonids (Atlantic Salmon & Trout)									47184	13.15		
A	Freshwater Finfish (not Salmonids)			270	9.51								
A	Silver Perch					246	12.24					53	11.81
A	Barramundi					62	15.18					2931	9.38

WC or A	Taxa	South Australia		Victoria		New South Wales		Western Australia		Tasmania		Queensland	
		Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})	Weight sold (t)	Price ($ kg^{-1})
A	Fish (e.g. Barramundi, Yellowtail Kingfish, Trout)							799	11.24				
A	Abalone	334	34.13	436	33.81					79	32.20		
A	Blue Mussel	1577	1.95	1014	4.18			147	4.31	941	4.00		

3.1.2. South Australian Fishermans Co-Operative Limited (SAFCOL) data

The SAFCOL Central Fish Market is the major wholesale seafood market in Adelaide. Some fish from aquaculturists also tend to bypass such wholesale markets (e.g. Atlantic Salmon). As such, the figures provided are representative of the weight of product sold and price per kilogram obtained for the listed taxa. The data presented for 2016 (Table 3.2) indicates that the highest priced finfish species at the time was Callop (also known as Golden Perch and Yellowbelly), a freshwater species farmed primarily in ponds in New South Wales as it is challenging to rear in more intensive systems, particularly RAS. Also, at the time the prices above \$15.00 kg^{-1} for finfish: Bream (primarily Black) \$19.02 kg^{-1}, Flounder (primarily Greenback) \$15.59 kg^{-1}, Blue Eye Trevalla \$15.51 kg^{-1}, Tuna (primarily Yellowfin) \$18.68 kg^{-1} and Whiting (King George) \$20.29 kg^{-1}; the freshwater crustacean: Yabbies \$17.13 kg^{-1}; and the Cephalopods: Octopus \$17.51 kg^{-1} and Squid \$16.15 kg^{-1}. While many of these species have been propagated and/or reared in Australia or overseas, only the aquaculture of the Yabbie and ranching of Southern Bluefin Tuna has so far been successfully commercialised. Reasons for the initial lack of success with the other species has ranged from low survival of early life stages (King George Whiting), slow growth (Black Bream and King George Whiting) and early maturation (Greenback Flounder); although further R&D might overcome such issues in the future.

Information in Table 3.2 also highlights the weight and value of finfish species sold in Adelaide in 2016 that were both wild-caught and aquacultured in Australia: 22 tonnes of Mulloway at \$9.90 kg^{-1}, 12 tonnes of Rainbow Trout at \$10.40 kg^{-1}, 21 tonnes of Barramundi at \$11.58 kg^{-1}, and 6 tonnes of Yellowtail Kingfish, a major South Australian aquaculture species, at \$14.09 kg^{-1}. Such information suggests for these species the cost of aquaculture production needs to be below \$8.00-11.00 kg^{-1} for aquaculture to be profitable.

Table 3.2: SAFCOL Central Fish Market sale price and weight for taxa sold for the year 2016. Dark green >$20 kg^{-1}, light green $15-20 kg^{-1}, yellow $10-15 kg^{-1}, light red $5-10 kg^{-1} and dark red <$5 kg^{-1}. Taxa mentioned in brackets after some sale identifier names are added by the author after discussion with SAFCOL (source: SAFCOL 2017, unpublished).

Sale Identifier (typically species)	Sum of weight (kg) Sold	Sum of value of sales ($)	Average price ($ kg^{-1})	Count of date (i.e. no. days sales occurred)
1kg Octopus Raw	5	135.00	27.00	1
200g Octopus Steamed	10	140.00	14.00	1
250g Octopus Raw	10	115.00	11.50	1
Barramundi	21,104	244,472.18	11.58	126
Boarfish Whole	1,888	12,623.15	6.69	37
Bream Bony	183	484.20	2.65	10
Bream Whole	3,152	59,960.41	19.02	90
Callop Whole	1,981	41,323.00	20.86	73
Carp Whole	4,505	10,153.46	2.25	65
Cod	9	36.00	4.00	1
Cod Ghost	1,418	8,728.65	6.16	22
Crab Cooked	4,973	83,618.12	16.81	71
Crab Mud	5	77.50	15.50	1
Crab Sand	2,791	19,779.58	7.09	33
Crab Uncooked	12,320	154,634.04	12.55	95
Cuttle Fish	21	215.30	10.25	7
Flathead Whole	33,164	290,610.93	8.76	108
Flounder Whole	2,452	38,215.74	15.59	51
Garfish Whole	76,873	883,842.16	11.50	124
Groper Whole	246	3,100.51	12.60	6
Herring Whole	42,501	192,133.93	4.52	121
Kingfish Yellowtail Whole	6,017	84,784.22	14.09	74
Leather Jacket	4,222	39,786.35	9.42	86
Mackeral Whole	5,767	51,155.24	8.87	55
Misc Fish	9,286	70,710.88	7.61	109
Mixed Fish	8,560	73,301.31	8.56	121
Morwong Whole	557	3,987.56	7.16	34
Mullet Coorong	15,509	139,695.15	9.01	86
Mullet Jumping	4,146	22,402.68	5.40	47
Mullet Red	555	7,351.35	13.25	82
Mullet Whole	9,820	32,933.57	3.35	72
Mulloway Whole	22,235	220,180.97	9.90	101
Nannygai	1,928	23,140.22	12.00	52
NZ Blanched Mussels	67	512.00	7.64	6

NZ Snapper	8,362	119,622.20	14.31	48
Octopus	233	4,078.79	17.51	7
Oysters	16,140	164,528.96	10.19	73
Perch Ocean	46	253.00	5.50	1
Pilchards IQF (Australian Sardines)	6,415	23,531.42	3.67	64
Redfin Whole	593	4,955.08	8.36	53
Salmon Trout Whole	23,157	48,782.12	2.11	90
Salmon Whole (Western Australian)	16,577	45,828.69	2.76	77
Sand Whiting	140	776.00	5.54	6
Shark	1,437	5,433.77	3.78	52
Shark - Bronze Whaler	10,652	78,364.05	7.36	84
Shark - Gummy	4,267	47,621.91	11.16	73
Shark - School	2,082	20,558.83	9.87	50
Shark Fins	115	1,452.65	12.63	24
Snapper Red	1,914	9,264.61	4.84	8
Snapper Whole	79,875	958,562.41	12.00	106
Snook Fillets	30	414.00	13.80	1
Snook Whole	13,706	89,771.20	6.55	101
Squid	38,859	627,673.03	16.15	122
Squid - Frozen	800	9,490.50	11.86	15
Squid Wing & Tips	1,140	2,662.20	2.34	26
Sweep Whole	131	1,245.10	9.50	21
Terakihi	100	1,086.37	10.86	6
Trevalla Blue Eye	1,047	16,243.55	15.51	29
Trevally Fillets	17	115.60	6.80	1
Trevally Whole	2,751	24,921.49	9.06	53
Trout Rainbow	11,711	121,830.48	10.40	28
Trumpeter	5,782	13,294.00	2.30	87
Tuna Whole (Yellowfin)	6,468	120,791.39	18.68	99
White Bait	177	1,307.10	7.38	9
Whiting Weedy	34	90.50	2.66	2
Whiting Whole (King George)	27,453	556,921.24	20.29	116
Wings	4,532	16,667.66	3.68	86
Yabbie Whole	2,977	50,997.85	17.13	34
Yellow Fin Whiting Whole	22,208	240,522.73	10.83	111
Yellowtails	2,886	18,065.18	6.26	24
Grand Total	**613,094**	**6,262,066.02**	**10.21**	**3756**

3.1.3. IGA Pasadena Supermarket data

Seafood sales information was collected by direct observation for about six months (25 March – 5 November 2017) from the IGA Pasadena supermarket, one of the newest and largest supermarkets in Adelaide that stocks one of the largest ranges of local products. The purpose of this was to appreciate the increasing diversity of product now sold in supermarkets; the nature of the product offered to the customer (e.g. whole or filleted) and the approximate mark-up on processed product; and the difference between product wholesale and retail market prices.

Higher priced species (Table 3.3, dark green) include Blue Eye Trevalla, Callop/Golden Perch, Black Bream, Deep Sea Perch, Flathead, Flounder (Greenback), Garfish, King George and Silver Whiting, Silver Trevally, King Prawns, Ling Fish, Snapper, Squid, Tuna and Yellowtail Kingfish. Examples of the whole (HOGG - head on, gilled and gutted) and fillet prices of three of the commonly aquacultured species were at the time, respectively: Rainbow Trout, \$18.56 kg^{-1} and \$26.70 kg^{-1}; Barramundi, \$19.99 kg^{-1} and \$38.81 kg^{-1}; and Yellowtail Kingfish, \$21.77 kg^{-1} and \$38.85 kg^{-1}. The considerably higher price of fillets was primarily a function of processing costs, particularly labour, and the product recovery rate following the processing (e.g. Yearsley 2000).

In general, the diversity of product at the IGA Pasadena supermarket during the period of observation was lower than at the SAFCOL Central market, although a few different species were sold. As expected, the relative price of species was usually comparable, although the actual price at the retailer, IGA, was higher than at the wholesaler, SAFCOL. A comparison of the prices of Barramundi, Rainbow Trout and Yellowtail Kingfish (Table 3.3) reveal that the whole fish prices at the retailer (IGA) were 1.55 – 1.77 times greater than those of the wholesaler (SAFCOL).

To maximise the sale price of their product, many aquaculturists vertically integrate their business to undertake processing within the company, supply supermarkets and even restaurants directly, and also value-add through the production of additional products.

Table 3.3: IGA Pasadena supermarket weekend seafood prices between 25 March – 5 November 2017. Dark green >$20 kg^{-1}, light green $15-20 kg^{-1}, yellow $10-15 kg^{-1}, light red $5-10 kg^{-1} and dark red <$5 kg^{-1}.

	Whole fish		Fish fillets	
Taxa	Price ($ kg^{-1})	No. of data	Price ($ kg^{-1})	No. of Data
Yellowtail Kingfish	21.77	9	38.85	7
Jumping Mullet	11.49	2		
Coorong Yellow Eyed Mullet	15.49	8	24.74	8
Mullet	12.99	2		
White Bait	16.99	1		
Snapper	25.54	11	45.66	9
Salmon Trout	10.37	8	17.59	10
Bonito	19.59	5		
Leather Jacket (skinned)	7.00	2		
Ocean Jacket (skinned)	9.36	8		
Mackerel	11.39	5	12.99	1
Yellowtail Mackerel	12.74	4		
Spanish Mackerel			32.99	1
Barramundi (baby)	19.99	9	38.81	11
Bluefin Tuna (steak)			64.99	2
Yellowfin Tuna (steak - Aust & Indon)			38.74	8
King George Whiting	32.16	6	59.29	10
Silver Whiting	22.99	2	39.42	7
Flounder	24.99	6		
Black Bream	31.32	3		
Red Snapper	14.99	1	38.66	9
Tommy Ruff	11.74	4	28.39	10
Mulloway	18.49	2	38.37	8
Atlantic Salmon			32.90	11
Rainbow Trout	18.56	7	26.70	7
Boar Fish			35.99	5
Swordfish (steak)			37.09	10
Marlin (steak)			26.12	8
Snook	12.56	7	24.77	9
Blue Grenadier (Aust & NZ)			19.32	9
Flake (Shark)			28.39	10
Garfish	21.56	7	44.44	11
Lingfish			39.24	8
Knife Jaw			28.99	1
Deep Sea Perch			44.99	7
Flathead			46.55	7
Deep Sea Cod			24.99	4

Callop	32.99	1		
Blue Eye Trevalla			49.99	1
Silver Trevally	22.99	1		
Skate Fillets			14.39	5
Deep Sea Bream			19.99	2
Sardine			29.99	1
Sand Crab	15.99	1		
Blue Swimmer Crab (uncooked)	19.99	8		
King Prawn (X large - cooked)	33.66	3		
Squid (skinned)	28.74	4		
Octopus (baby)	19.99	1		
Oysters (doz half shell)			15.99	2

3.1.4. Mark Lee Fish Farm data

The Mark Lee Fish Farm, St Kilda, is a South Australian RAS producer of Barramundi and distributes a wide range of other species that are brought on-site from suppliers in South Australia and interstate, maintained alive and then retailed to customers. The farm was visited on a couple of occasions in 2016 and 2017 as no other marketer was located in South Australia that sold many of the key Australian temperate, native freshwater aquaculture species, enabling price comparisons to be obtained from one supplier for Barramundi, Murray Cod, Jade Perch, Silver Perch and Golden Perch. Table 3.4 highlights that on the 7 July 2017 these species were selling, respectively, at \$15.99-19.99 kg^{-1}, \$27.99 kg^{-1}, 27.99 kg^{-1}, 27.99 kg^{-1} and \$32.00 kg^{-1}, with the latter considered the better eating species, but the more challenging to aquaculture because of its reluctance to consume pelleted feeds. The lower market price of aquacultured Barramundi is economically feasible because of its lower cost of production, which in large part is attributable to the high stocking densities, fast growth and hardiness of this species.

Information in Table 3.4 also highlights the high value of wild-caught Rock Lobster (\$115 kg^{-1}); Mud Crab (\$38-46 kg^{-1}); Pipi(\$16.99 kg^{-1}); and aquacultured Abalone (\$54.99-79.99 kg^{-1}). Of these species, only the aquaculture of the latter has so far been successfully commercialised in South Australia; although R&D has on occasion been identified to be of interest for the other species.

Table 3.4: Live seafood prices at Mark Lees Fish Farm, 7 July 2017. Dark green >$20 kg^{-1}, light green $15-20 kg^{-1}, yellow $10-15 kg^{-1}, light red $5-10 kg^{-1} and dark red <$5 kg^{-1}.

Species (live)	Price ($ kg^{-1})
Farmed Barramundi (1st grade)	19.99
Farmed Barramundi (2nd grade)	15.99
Farmed Murray Cod	27.99
Farmed Golden Perch/Callop	32.00
Farmed Jade Perch	27.99
Farmed Silver Perch	27.99
Farmed Baby Abalone	54.99-77.99
Farmed Baby Abalone (frozen)	44.99
Wild-caught Pipi	16.99
Wild-caught Southern Rock Lobster	115
Wild-caught Crab	12.00
Wild-caught Mud Crab (Darwin)	38-46

3.1.5. Other potential aquaculture species based on market information

A review of Yearsley et al. (1999) and Yearsley (2000), which provide a range of categorical and/or quantitative information relevant to many of the freshwater and marine finfish and shellfish caught and/or farmed in Australia, and discussion with local aquaculturists, seafood wholesalers and retailers, identified a number of other high price, wild-caught species that might have potential for aquaculture from a marketing perspective. Species are:

Blue Eye Trevalla

Blue Eye Trevalla (*Hyperoglyphe antarctica*) is a temperate high-priced Australian marine species that is excellent to eat, grows to reasonable size, is of good shape and appearance, has a good flesh recovery rate, is able to be cooked in many ways, has few bones and nutritionally has a good Omega-3 profile.

Cobia

Cobia (*Rachycentron canadum*) is a moderate-priced tropical marine species that is good to eat; grows rapidly and to a good size; is of good shape and appearance; has a reasonable flesh recovery rate; is able to be cooked in many ways; has few bones; and nutritionally has a good Omega-3 profile, although less than the comparable temperate species, Yellowtail Kingfish.

Coral Trout and Queensland Grouper

Coral Trout (*Plectropomus spp.*) and Queensland Grouper (*Epinephelus lanceolatus*) belong to a tropical group of marine species, often referred to loosely as grouper. They are high-priced and excellent to eat; grow to reasonable size; are of good shape and appearance; have a good flesh recovery rate; are able to be cooked in many ways; have few bones; and nutritionally have a good Omega-3 profile, although less than temperate and cold-water species.

Hapuku

Hapuka (*Polyprion oxgeneios*) is a cool temperate, high-value, marine species favoured because of its flesh quality and texture, but not commonly seen in markets because of the low catch quantities in Australia and New Zealand.

Macroalgae and microalgae

Commercial aquaculture of many different macroalgal species is substantial in Asia and becoming more common in other parts of the world along with microalgal culture, which may be of freshwater or marine species; although few commercial algal operations of either form exist in Australia. Actual and potential products from algae are diverse and include from lower to higher value: energy production, fertilisers, aquatic and terrestrial animal feeds, human foods, cosmeceuticals, nutraceuticals and pharmaceuticals (e.g. Roos et al. 2019).

Mud Crab

Mud Crab (*Scylla serrata*) is a high-priced tropical marine species considered to be excellent to eat; grow to a large size and with a good flesh recovery rate for a crustacean; are of good shape and appearance; and versatile for food preparation.

Red Emperor

Red Emperor (*Lutjanus sebae*) is a high-priced tropical marine species considered to be excellent to eat; grow to a reasonable size; are of good shape and appearance (including red colour); have a good flesh recovery rate; able to be cooked in many ways; have few bones; and nutritionally have a good Omega-3 profile, although less than temperate species.

Sea Cucumbers

Sea Cucumbers (e.g. *Holothuria scabra* and *Stichopus mollis*) can be marine tropical or temperate depending on the species, of which a number have a high market price (e.g. \$250-1,000 kg^{-1} (dried and gutted)). The Tropical Sandfish (*Holothuria scabra*) is the preferred tropical species and the Brown Sea Cucumber (*Stichopus mollis*), which closely resembles the highly valued Japanese Sea Cucumber (*Apostichopus japonicas*), the preferred temperate species. Sea cucumbers (the flesh and intestine) can also be value-added to produce Chinese health products.

Sea Urchins

The Purple Sea Urchin (*Heliocidaris erthrogramma*) is a temperate endemic Australian species with a high market price (e.g. \$2,000-3,000 kg^{-1}) for its roe (gonads), which comprises only about 9% of an urchin's total wet weight. There is an excellent Asian export market and slowly growing Australian market. Sea Urchins (the shell, spines and gonad) can also be value-added to produce a range of traditional Chinese health products, including anti-inflammatories.

Sturgeon and Turbot

Aquaculture entrepreneurs and representatives of RAS construction companies with overseas experience (i.e. Asia, Europe, USA) and who were interested in establishing aquaculture ventures in South Australia, frequently raised the possibility of culturing species of sturgeon and turbot.

The major sturgeon species aquacultured, for both meat and caviar, are the Siberian Sturgeon (*Acipenser baeri*), Beluga Sturgeon (*Huso huso*), Ostrei Sturgeon (*A. gueldenstaedtii*), Sterlet Sturgeon (*A. ruthenus*), the hybrid Bester Sturgeon (female Beluga x male Sterlet) and in the USA, the White Sturgeon (*A. transmontanus*) (Bronzi et al. 2011). Sturgeon caviar (their eggs) is a very high price (e.g. \$1,100-1,500 per kilogram wholesale), although the exact amount depends on the species and manner in which it was harvested. It has been suggested during discussion with local fish sellers that sturgeon fillets might retail for about \$25-35 kg^{-1} in Australia, but this is uncertain.

The Turbot (*Scophthalmus maximus*) is a marine left-eyed flatfish found primarily close to shore in sandy shallow waters throughout the Mediterranean to the North Atlantic. It is high-priced, grows large (100 cm and 25 kg), has a delicate flavour and is versatile for cooking.

3.1.6. Market summary

A diverse range of species have been identified with aquaculture potential based on marketing information demonstrating a high to moderate sale price. These include species of algae, crustaceans, finfish, molluscs and others from freshwater, estuarine and marine environment in South Australia, Australia and overseas. Some of the species are already aquacultured, some subjected to R&D, but because of a range of biological and/or technical challenges have not been commercialised, and a few not yet investigated at all.

Importantly, comparison of the market price of existing Australian aquacultured products highlights they typically have a high to moderate price, but some have a low price compared to wild-caught products. It has also revealed that market price can fluctuate substantially with season due to variability in wild-caught product supply. This emphasises that it is not just product price that determines a species commercial potential, but the profit margin, which is highly dependent on the cost of production, with this often determined by the biological characteristics of a species and the nature of the system in which it is cultured.

3.1.7. Biological characteristics

Following market viability, species selection frameworks tend to prioritise the need for a species that is biologically suited to aquaculture. This includes parameters such as ease of breeding; length of breeding season; fecundity of female broodstock; and simplicity and survival of stock as they are reared through the larval, nursery and growout stages. Also, of great importance is their growth rate, in particular the time to reach market size, not just of some of the faster growing stock but of the whole stock population. Behavioural parameters, such as hardiness of the species to be stocked at moderate to high density; susceptibility to stress, disease and pests; and the species affinity to cannibalism are also important as they can be important determiners of mortality rate (Alvarez-Lajonchere and Ibarra-Castro 2013) and influence the efficiency that can be achieved with the culture system in use and cost of production. It is also important to consider reproductive parameters, particularly accessibility to seed and brood stock. Accessibility to and availability of stock is likely to be influenced by spawning, fecundity or egg quality (Le Francois et al. 2002).

To various extents, once criteria have been considered, short-listed species can be weighted and scored to provide a quantitative reasoning behind species selection (Quemener et al. 2002, Alvarez-Lajonchere and Ibarra-Castro 2013). Further parameters that have previously been considered beyond market and biological parameters include availability and type of food consumed. Feed accounts for upwards of 50% of an aquaculture operations costs. It is preferable to culture a species with an affinity to dry feed as this is more easily transported and stored, leading to less waste.

The environmental tolerances and optima of a species also need to be considered (e.g. Table 3.5), while recognising that some land-based culture technologies such as RAS enable the culture environment to be matched with the environmental optima of the culture species, although always at a monetary cost.

Table 3.6 provides a brief synopsis of the key biological characteristics of the species identified as having the most aquaculture potential from the market research, enabling determination of a much shorter list of species potentially suited to aquaculture in 2W2W. Information has been adapted from NSW Government (2009), Gooley and Gavine (2003) and Anon (2013), as well as obtained from other sources.

Finfish species considered to have the greatest biological potential for aquaculture in South Australia at present are: Barramundi, Greenback Flounder, Jade and Silver Perch, Murray Cod, Mulloway, salmonids (e.g. Rainbow Trout – either in fresh or saltwater and Atlantic Salmon), Snapper, and Yellowtail Kingfish. These species can be readily fed, handled, propagated, stocked at reasonable density; have good FCR and growth rates; their common diseases and pests can be managed; and they have environmental optima and tolerances that allow them to be cultured in suitably matched fresh or saltwater sources. However, as salmonids are cold-cool temperate species they are less suited than the others to the 2W2W region, and more likely to be aquacultured in the south of South Australia.

Table 3.5: Temperature and salinity range for breeding and growout (adapted from: NSW Government 2009, Gooley and Gavine 2003, Anon 2013).

Species	Optimum temperature (°C)		Salinity (ppt)	Time to market (months)
	Hatchery	Growout	Growout	
Brine Shrimp		25-30	30-180	
Mud Crab			28-34	
Prawns – Black tiger	28-32	25-32	15-25	
Prawns – Kuruma	25-30	20-28	“	
Prawns – School	-	21-27	“	
Prawns – Freshwater		23-32	<11	
Marron		20-24 (4-30)	<6-8 (0-15)	12-24
Redclaw	27-30	27-32 (23-31)	<6-8	6-12
Yabbies	21-24	25-28 (2-36)	<6-8 (0-12)	6-12
Atlantic Salmon		10-16	0-35	12-24 (fw), 24-36 (sea)
Barramundi	27-30	26-30 (16-35)	0-35 (0-40)	0.5-0.8 kg in 12, 5 (RAS); 2-3 kg in 18-24
Black Bream		22-24	24 (3-40)	
Eels	-	23-28	0-5 (0-35)	18-24 (from elver)
Flounder		18-20	>15	
Yellowtail Kingfish	21-24	15-25		
Mahi-Mahi	25-30	25-30		
Mullet		3-35	0-38	
Mulloway	21-26	14-30		
Murray Cod	19-21	23-25 (20-26)	<8	0.6-1.3 kg in 10-18 (RAS) 24
Perch - Golden		23-28	<8?	
Perch - Jade		20-30	<5	
Perch - Silver	20-25	23-28 (0-28)	<4 (0-15)	10-24 (ponds)
Snapper	21-24	20-28 (17-30)	>8	
Trout – Brown	6-10*	8-18 (4-19)	0-35	12
Trout - Rainbow	9-14*	8-18 (10-22)	0-35	9 (ponds)
Abalone		15-18	34-37	
Blue Mussels		12-20 (2-29)	>15	
Pacific Oyster		20-30	23-28	
Macroalgae – *Gracilaria*		20-30	15-24	
Macroalgae – *Ulva spp*			30	
Microalge – *Dunaliella*		12-35	>200	

**for spawning and egg production*

Table 3.6: Key biological characteristics of the major species that have been researched or are commercially aquacultured in Australia, with colours denoting their suggested potential for land-based aquaculture in the 2W2W (green – greatest potential, yellow – moderate potential and red - least potential).

Common name	Scientific name	Commercial aquaculture status (occurring/ stopped/ R&D and not started)	Aquaculture systems in use/used	Comments in relation to land-based aquaculture in 2W2W	Key references
Abalone (Greenlip (n SA), Blacklip and their hybrid)	*Haliotis laevigata* (Greenlip)	Occurring WA, SA, VIC and TAS.	Hatchery & nursery – partial RAS Growout - pump ashore land-based tanks and raceways	A temperate water Australian marine species ideally cultured using oceanic waters where possible. Reaches market size in about three years. In South Australia is farmed in water temperature of about 11-22°C and salinities 35-38 ppt; above this salinity and temperature, stress induced mortalities become common. High dissolved oxygen and low free ammonia levels are required for good growth (dissolved oxygen levels <5.91 mg L^{-1} and free ammonia >0.158 mg L^{-1} decrease growth by 50%). Hatchery and growout methodologies are well known. Abalone are generally ongrown in land-based tanks and raceways adjacent the coast using large volumes of high quality flow-through water from the sea, although some aquaculture has been tried in sea cages and ranching on in-sea artificial reefs. On-land they are typically fed natural feeds during the nursery stage and manufactured feeds during ongrowing. While Greenlip Abalone occur naturally offshore of the 2W2W at Tickera in Spencer Gulf, inshore waters are considered to be too warm and saline in summer for a pump-ashore facility without further costly water environmental management.	e.g. Hone et al. (1997), Hutchinson and Vandepeer (2005)
Barramundi	*Lates calcarifer*	Occurring WA, SA, VIC, NSW, QLD and NT.	Hatchery – partial RAS, pond (nursery). Growout – RAS (NSW, SA, VIC), ponds (QLD, NT), and sea cages (QLD, WA)	A tropical estuarine species that occurs in Australia and Asia and can be ongrown in fresh or saltwater, although spawning and larval rearing is in saltwater. Growth to 400-600 g plate size in about 6-12 months and 2-3 kg in another 12 months. Can be grown at high density (30-80 kg m^{-3}). Hatchery and growout methodologies are well known. Only feasible in RAS in the 2W2W as Barramundi require relatively high temperatures for good growth (25-30°C, optimum 28°C); feeding stops at <20°C and high mortalities occur at <13°C. FCR of 1.5-2.1 are common in ponds but about 1:0.9-1.2 in RAS depending on fish size.	e.g. Jones et al. (2013), Hathurusingha and Davey (2014), Queensland Government (2016a); NSW Department of Primary Industries (2016a); Robarra (2017); MainStream Aquaculture (2017)

			.	Grading to manage cannibalism is important in the hatchery/nursery. Ensuring marketed fish are not affected by off-flavours (geosmin and 2-methylisoborneol) by purging in clean water after growout is important. Heating water, even for RAS, is typically energy demanding and costly, although less so than cooling. Heating cost can be reduced by using groundwater with elevated temperature, other sources of waste heat, and/or off-setting costs using solar water heating systems. Barramundi are often farmed in aquaponics systems where water temperatures are often elevated.	
Black Bream	*Acenthopagrus butcheri*	Stopped; growth rate too slow.	Hatchery – partial RAS, pond (nursery). Growout – ponds (SA, WA)	An Australian temperate estuarine species that can be ongrown in fresh or saltwater, although naturally spawning in the upper reaches of rivers and with juveniles abundant in the estuaries. Hatchery and growout methodologies are well known. Growth is very slow (Doupe et al. 2005 indicate a 33% increase would be needed for economic viability) even at an ideal temperature of 22-24°C, but the species can be grown in high density and is hardy. It will survive and growth in salinities from 0-48 ppt but growth and FCR are optimal at 24 ppt. It has been reported that Japanese researchers successfully crossed Black Bream and Snapper to obtain a faster growing, hardy hybrid but that it was not successfully marketed as it differed in look from natural Black Bream and Snapper.	e.g. Jenkins et al. (1999), Norriss et al. (2002), Partridge and Jenkins (2002), Sarre et al. (2003), Doupe et al. (2005), Anon (2013)
Blue Eye Trevalla	*Hyperoglyphe antarctica*	Not started.	N/a	A marine cool temperate benthic carnivorous deepwater species (adults at 200-900 m but juveniles at the surface and mid water) that grows to about 50 kg and 1.4 m in length and has a life span of 76 years. Caught from the wild in small quantities in southern Australia and in larger quantities New Zealand. Reproductive maturity in the wild occurs at about 11-12 years for females and 8-9 years in males, spawning is in summer and autumn and a 1.6 kg weight is achieved at about 400 mm fork length at about 2-3 years of age. Aquaculture has never been attempted despite the species being an excellent table fish caught from southern Australian waters, primarily because of the many perceived challenges to commercial success – accessibility of stock, lengthy time to maturity and slow growth.	e.g. AFMA (2016), Smallwood et al. (2013)

Blue Mussel	*Mytilus galloprovincialis*	Occurring WA, SA, VIC, TAS and NSW.	Hatchery or natural in-sea capture of spat Growout – in-sea on longlines	A marine temperate species, possibly native but more likely occurring in other countries as well) that grows well on aquaculture longlines in the sea at 16-22°C but has a tolerance of about 5-29°C. It reaches a market size of 75–100 mm in shell length in about 12-18 months. Hatchery and growout methodologies are well known. Blue Mussels are not considered suitable for land-based aquaculture due to the species low market value.	e.g. NSW Department of Primary Industries (2016b)
Brine Shrimp	*Artemia salina; Parartemia sp.*	Stopped. WA and SA.	RAS and pond systems	*Artemia* occur in many countries, but *Parartemia* is native to Australia. An important food source for the aquarium trade and aquaculture, the latter primarily for feed for the larval stage of marine finfish during a short period of their development. BrineShrimp are generally marked as 'cysts' (encapsulated eggs) for aquaculture or as adult stage animals in small frozen packages for the aquarium trade. Brine Shrimp are typically grown at temperatures of 12-35°C and salinities of 30-35 to 150-180 ppt (their many predators do not occur above 100 ppt so salinities above this are optimal). Large Brine Shrimp operations are usually aligned with salt lakes for salt production and/or production of the microalgae *Dunaliella salina* for beta-carotene production. Brine Shrimp production methodology is well known, but quite different for the production of cysts as compared to adults. A unique poly-tank Brine Shrimp production facility with specialised filtration and harvesting system enabling a high biosecurity capacity, was developed at Port Gregory, Geralton, WA in association with BSAF (ex-Cognus), the company that owns the microalgal operation adjacent as well as the one just north of Whyalla in South Australia. A few small RAS and pond Brine Shrimp production systems have operated in South Australia in the past to supply the aquarium trade, including one in the 2W2W near Tickera. Paratemia sp., a type of native Brine Shrimp, has been noted to bloom occasionally in the saline lakes at Port Augusta, South Australia.	e.g. Lavens and Sorgeloos (1996), Government of Western Australia (2010), Coerco Agriculture (2017)
Crabs Blue Swimmer	 *Portunus pelagicus*	 Blue Swimmer: Stopped;	Hatchery – partial RAS (some capture from wild) Growout – ponds and	Both species are estuarine and coastal and occur in many countries, including Australia. The Blue Swimmer Crab is temperate to sub-tropical with the fishery in SA at its southern latitudinal limit. The Mud Crab is a tropical species. For the Blue Swimmer Crab water salinity of 26-35+ ppt and temperature of 25-32°C is ideal for optimal culture; survival and growth is greatly reduced at <15 ppt. Grows rapidly to a market size of about 150 mm carapace width and 100+ g in 4-5	Blue Swimmer Crab: e.g. Smallridge (2002), Ramano and Zeng (2008)

Mud Crab	*Scylla serrata*	has been researched/ farmed in QLD and SA. Mud Crab: some growout in prawn ponds in QLD.	RAS (particularly for 'soft-shell' product)	months (faster than Mud Crab that take about 6-7 months to grow from just post-larvae to market size). For the Mud Crab the five larval stages reared in the hatchery take about 3 weeks at 27-28°C to develop from a planktonic existence to metamorphose into a bottom dwelling juvenile crab. Juvenile and adult crabs have a tolerance of about 20-32°C and 10-45 ppt for survival, with optimal growth at about 15-25°C. Providing shelters and grading are important for managing cannibalism during the molt phase for both species, as is provision of an optimal diet (prawn feeds have generally been used to date). While Blue Crab aquaculture has been attempted in the 2W2W it was not successful, most likely because of water quality issues affecting larval survival in the hatchery. The issues experienced could probably be addressed, but optimal environmental conditions for growout cannot be provided year round except within an intensive a RAS. Enquires have been received from an entrepreneur interested in using South Australian saline groundwater and a RAS for Mud Crab culture. Crab aquaculture is believed feasible in the 2W2W, particularly if undertaken using intensive RAS so that optimal water temperatures and growth and harvesting can be maintained all year. The optimal temperature for Blue Crab as compared to Mud Crab culture is more suited to the 2W2W, and they reach market size in about half the time but have only about half the sale value.	Mud Crab: e.g. Queensland Government (2016b), Shelley and Lovatelli (2011)
Cobia/Black Kingfish	*Rachycentron canadum*	Occurring QLD.	Hatchery – partial RAS. Growout – ponds and sea cages	A tropical marine species that can be very fast growing; up to 5-6 kg annum^{-1} at low stocking rates but more typically over two years, temperatures of 20-28°C, salinities of 34-36 ppt and dissolved oxygen levels >5 mg L^{-1}). Much lower growth rates have been experienced under suboptimal conditions. Cobia are now being produced commercially in low volume in QLD, primarily in converted prawn ponds. FCR of about 1.3 have been achieved for juvenile fish and 1.8-2.2 for larger cultured fish Hatchery and growout technology is known, but due to the infancy of the industry there is ongoing potential for further improvements and market development. The species grows as about double the rate of Yellowtail Kingfish. Disease issues have affected industry development in some locations. While the species is very rapid growing, it is being pursued as an aquaculture species in many tropical–subtropical regions and in time production is likely to greatly escalate	e.g. Benetti et al. (2010), Lee et al. (2015)

				and prices decline. With the need to also heat the water to a high temperature, the species is not recommended for RAS culture in the 2W2W for the longer term.	
Eel Tailed Catfish	*Tandanus tandanus*	Stopped. SA, NSW and QLD.	Hatchery – partial RAS. Growout – dams and ponds.	Hardy, warm temperate Australian freshwater species. Was considered a likely Australian pond based aquaculture species in the 1990s but the industry has not grown, with the species typically bred in small quantities for the Aquarium Trade, Aquaponics and stocking of farm dams. Catfish have a broad temperature tolerance of about 4-38°C, but with a normal water temperature range of 15-30°. Spawning occurs at 20-24°C. Catfish are naturally carnivorous but feed well on pellets; they reach table size in about 2 years in extensive pond culture systems; faster in more intensive systems. Issues that have inhibited the species development include: broodstock nest construction for egg laying and larval hatching, relatively slow growth rate to larger size, spines that make handling challenging, undesirable appearance for marketing with the market thus primarily for fillets, and low market price. As such, the species is not recommended for land-based aquaculture in the 2W2W.	e.g. McCormack (2017a)
Eels Long Fin Eel Short Fin Eel	*Anguilla reinhardtii* *Anguilla austalis (a more temperate species)*	Occurring SA, VIC, TAS, NSW and QLD.	Hatchery – not applicable, not able to be bred. Growout - extensive (impoundments or ponds) and intensive (tank based) systems	Hardy sub-tropical to temperate Australian and New Zealand species that live in freshwater but migrate to the ocean to breed. Every year adult eels (silver eels) migrate from the east coast of Australia (TAS to QLD) and NZ to the Coral Sea, where it is thought they spawn in deep water before dying. The eggs hatch and larval eels are carried by ocean currents back to the continental shelf, where at about 18 months of age they metamorphosise into 'glass eels'. The glass eels are carried by the currents back to shore and the coastal estuaries, developing into 'elvers' of 8-20 cm in length at 1-3 years of age, with a similar appearance to adult eels. The elvers migrate upstream where they mature into adult eels and can live for 15-20 years. Juveniles eels (glass eels and elvers) are caught from the wild, stocked into nursery tanks and then into growout facilities where they are cultured to market size. Juvenile eels can be challenging to source, particularly in South Australia where they are scarce in the wild and interstate supplies difficult to secure as wild caught stock numbers are carefully managed. Farming methodologies are well known. Eel growth and FCR is best between 23-28°C. Stocking rates in RAS are typically 80m^{-3} but can be as high as 200 kg m^{-3}; while in super intensive pond systems stocking rates can exceed the equivalent of 20 tonnes ha^{-1}. Under ideal controlled culture conditions grow to market size of 150-200 g in 12-18 months and 200-300 g after 18-24 months. FCRs of 1.5-2.1 have been achieved on pelleted feed. Size grading is required to reduce cannabilism.	e.g. NSW Department of Primary Industries (2016c); Queensland Government (2016c), Heinsbroek and Karnstra (1990)

					NSW DPI (NSW Department of Primary Industries) recommends pond stocking rates at <10 tonnes ha^{-1} and 50 kg m^{-3} with pH of about 7-8.0, alkalinity >20 mg L^{-1}, dissolved oxygen <3 mg L^{-1} and free ammonia – N <0.2 mg L^{-1}. Bacterial and fungal infections of galls eels from the wild are typically treated using a 10 ppt salt bath. Eel farming requires access to large volumes of water because of the high stocking densities and messy feeding behavior. NSW DPI recommends a water budget for intensive pond culture of >40ML ha annum^{-1}; much less is required for RAS.	
Freshwater Crustaceans Marron Redclaw Yabby	*Cherax tenuimanus* *Cherax quadricarinatus* *Cherax destructor*	Occurring Marron primarily in WA, and SA; Yabbies in WA, SA, VIC and NSW; and Redclaw in QLD and NT.	Nursery Ponds Growout Ponds	– -	All three Australian freshwater crustacean species have attracted significant commercial interest both within Australia and internationally because of their rapid growth and ready markets. Marron and Yabbies are temperate species whereas Redclaw are tropical. Marron require cooler conditions and better water quality, and are grown to a larger market size (120-180 g in 24-30 months) than Yabbies (typically 30-60 g in 6-12 months). Redclaw are typically moved from nursery ponds after 3-4 months to stock growout ponds where they reach a market size of 35-100 g in 6-9 months. Generally, ponds are dried between production cycles, stocked with juveniles produced in separate nursery tanks or smaller ponds, and harvested repeatedly with pots and traps, as well as drain harvested at the end of the production cycle. As such, commercial ventures use purpose designed ponds of about 1,000 m^{2} and 1.0-2 m deep rather than farms dams, provide shelters to reduce cannibalism, aeration to enhance water quality (particularly Marron and Redclaw), and rely on supplementing natural feeds with various pelleted grain based feeds. Average pond yields are around 1,600 kg ha^{-1}, with the best farms producing in excess of 3,000 kg ha^{-1}. Redclaw growout is optimal at 27-32°C, whereas Yabby growout is optimal at 23-28°C and salinities <8 ppt, with no growth <15°C or >34°C and high mortalities at >25 ppt. Yabbies could be aquacultured in extensive or semi-intensive systems in the 2W2W, wherever water is adequate, remembering that ponds will lose water rapidly because of the high evaporation rates that exceed rainfall. Some years ago a cooperative established in south-west Western Australia to bring together and coordinate stocking, harvesting and sales of yabbies from farm dams. A similar opportunity might exist in the farm dams of the 2W2W and surrounds. These three freshwater crustaceans have not successfully been commercially produced from intensive recirculation systems; they have always seemed to grow	Marron: Lawrence (2007); Fotedar et al. (2015) Redclaw: Queensland Government (2018a)

				better in ponds, most likely because of the availability of natural feeds on the bottom that they can scavenge.	
Golden Perch	Macquaria ambigua	R&D, not started. Primarily cultured in QLD and NSW.	Hatchery – partial RAS with nursery culture often in plankton enriched ponds. Growout – primarily in dams.	A hardy warm temperate to subtropical Australian freshwater carnivorous species, with four distinct regional populations; some considering the fish from the Lake Eyre Basin to offer the best prospects for aquaculture because of their believed greater environmental tolerances and faster growth. Golden Perch are identified to tolerate temperatures of 4-37°C and salinities <33 ppt. They feed adequately at 15°C but not at <12°C. Spawning is hormone induced and typically undertaken at about 25°C. Salinity is desirably maintained at <5 ppt; pH between 6.0-9.0 (6.5-9.5) and dissolved oxygen >4 mg L^{-1}. Hatchery and growout methodologies are well known, with Golden Perch having a more complex mating ritual than Silver Perch and reluctant to feed on manufactured pellet diets (the most significant commercial aquaculture challenge with this species). A larval weaning procedure has been developed but is slow (about 10 days) and is still limiting as some fish revert to preferential feeding on natural feeds when stocked in dams. While larval survival rates can be much higher (80%) than for Silver Perch between metamorphosis and the 15 mm fingerling stage, batches of eggs sometimes fail to hatch unlike for other comparable freshwater species. At about 15°C, growth takes 40 days from 1 to 25 g, 75 days to 40-50 g, 100 days to 108 g and 14-18 months to 350 to 1,000 g (growth in extensive dam systems which rely more on natural feeds are more variable and an average 400 g in this time is realistic for the majority of fish). Ongrowing ponds are stocked at about 20,000-100,000 fish ha^{-1}. After 9 months they may be counted and graded from nursery ponds and restocked in growout ponds at 5,000-21,000 fish ha^{-1}. The fish are omnivore but are fed on pellets developed for native finfish species. FCR are about 1.2:1 for fingerlings and 1.5-1.7:1 for growout in ponds where fish have been successfully maintained on pellets. Ponds are netted or 'wired' to prevent bird predation. Fish from extensive farm dams are desirably harvested at 1-2 kg and have been found to not need purging. Golden Perch, because of their weaning challenges, are not recommended for land-based aquaculture in the 2W2W, but are a suitable species for the stocking of dams and reservoirs for recreational fishing.	e.g. McCormack (2017b)

Greenback Flounder	*Rhombosolea tapirina*	Stopped. Considerable R&D done, and growout trails undertaken in TAS and VIC.	Hatchery – partial RAS Growout – ponds, tanks	A coastal and estuarine Australian warm temperate marine species with rapid early growth rate but a relatively small maximum size (compared to a few species of flat fish in Europe – e.g. Halibut and Turbot). Growout is undertaken in water temperatures of 10-18°C in the sea and 8-25°C in ponds. Indoors 17-18.5°C was optimal for growth. Hatchery and growout methodologies known. Stocking densities of 1-15 kg m^{-2} gave good growth; in Japan and Spain, respectively, flat fish have been grown out at 25-30 kg m^{-2} and 45 kg m^{-2}. FCR of 1.5-.2.1:1 have been achieved during growout and 1.2-1.5:1 in nursery. Most feeding occurs on the bottom. Maturation occurs at about 12 months and growth rates then slow, which is one of the key issues limiting aquaculture of the species. Small market plate size fish of 200-300 g produced in 20 months from hatch; preferred market plate size 300-400 g. Male broodstock have been found to be challenging to source in South Australia.	e.g. Purser (1996)
Hapuku	*Polyprion oxygeneios*	R&D (in New Zealand), not started.	Hatchery – partial RAS Growout – R&D in 20-70 m^3 tanks	A cool temperate marine grouper type species found in Australian and New Zealand waters that grows to a large size. It grows rapidly to about 1.4 kg in 12 months and 3.3-5.7 kg in about 30 months. Readily spawned in captivity at about 10-13°C, but fecundity, egg fertilization rate and growth of larvae are lower than for Yellowtail Kingfish. The nursery temperature for Hapuka is 14-19°C as compared to 20-23°C for Kingfish. Growth of juvenile Hapuka is best at 18°C as compared to 22°C, and 18-22°C is the upper temperature of larger Hapuka. No information exists on the species salinity tolerances, although it is likely to be best in oceanic conditions (35-37 ppt). Hapuka are endemic to South Australia, and might after further investigation be a potential suitable candidate in RAS where cooler water temperatures and oceanic salinities exist (i.e. outside the gulfs).	e.g. Symonds et al. (2014)

Jade Perch	*Scortum barcoo*	Occurring QLD, NSW, SA.	Hatchery – partial RAS Growout – ponds, RAS, tanks	A hardy, rapidly growing subtropical Australian freshwater species, but one that does not grow large so is best targeted at the plate size market. Optimal water temperatures for culture are 20-30°C (24°C ideal) and salinities <5 ppt. Like most native freshwater finfish species, general water quality characteristics are: pH 6.5-8.5, dissolved oxygen >4 mg L^{-1} and free ammonia <0.1 mg L^{-1}. Hatchery and growout methodologies are known. The larval stage is short and fingerlings will reach 30-50 mm in 8-12 weeks. In RAS they will grow from fingerlings to 450 g in 4 months and 800 g in 7 months, so a market size of 600-1,000 g should be attainable in 12 months. RAS stocking densities are typically 40-50 kg m^{-3} but higher is likely to be achievable. FCR are 1.2-1.6:1; the species does not feed much below 17°C. Growth rates rapidly decline below 20°C and with decreasing temperature they become increasingly stressed, with some handling mortalities occurring at 17°C and high mortalities typical at 13°C. Jade Perch culture in QLD is typically in 0.2-0.5 ha ponds with depths of 0.7-2.5 m. In South Australia, the species has been farmed commercially in small intensive RAS and aquaponic systems. Jade Perch are ideal for farming in aquaponics systems in temperate environments and have a niche market because of their high Omega-3 oil levels.	e.g. Queensland Government (2018b)
King George Whiting Yellowfin Whiting	*Sillaginodes punctata* *Sillago schomburgkii*	R&D, not started. SA.	Hatchery – partial RAS Growout - tanks	Coastal Australian marine temperate finfish species. King George Whiting has been found to be challenging at the hatchery stage and grows slowly at all life stages, whereas Yellowfin Whiting has been reported to be easier to propagate and rear, and grow more rapidly. For King George Whiting, egg incubation occurs at 16-22°C and 35-45 ppt, with metamorphosis occurring about 50-70 days post hatch at an optimal 20-24°C. Growth of fingerlings, about 120 days post hatch, occurs at 18-26°C, but is optimal at 22-26°C. Juveniles growth only about 7% faster at 26°C as compared to 20°C. Based on hatchery and nursery growth rates King George Whiting were estimated to take about 24-30 months to growth to a market size of 200 g and 30 cm length. The species consumes pelleted feeds lower in the water column or off the bottom and is typically a more passive feeder than many other aquaculture finfish species. FCRs during research were >2.91.	e.g. Ham and Hutchinson (2003)

		As the fish are elongate in shape, no plate-size market exists; they are sold filleted (larger fish) or whole (smaller fish). The recovery rate of fillets from whole gilled and gutted fish is 57% for 170-230 g fish and 62% for 230-340 g fish. The species is not recommended for land-based aquaculture in the 2W2W due to the challenges in optimising egg quality, the long larval life-cycle phase and slow growth rate during growout. However, these factors may be able to be addressed through more R&D. It would also be interesting to see whether a hybrid between King George Whiting and another faster growing species (e.g. Yellowfin Whiting) might be technically possible and result in improved biological characteristics while retaining marketability.	
Macroalgae	Occuring NSW.	Macroalgal culture is prolific in some countries overseas and of considerable interest as a potential area of growth in Australia, including South Australia (e.g. Roos et al. 2019), with the preferred long term strategy to be the cultivation of select species in land-based systems for multiple higher value marine bioproducts, with the algae obtaining their nutrients (e.g. nitrogen, phosphorus and carbon dioxide) from waste streams where possible. A few macroalgal beach drift harvest operations exist in Australia (e.g. Gather Great Ocean Group in South Australia; King Island Kelp Industries, Tasmania; and Australian Health Products, New South Wales) and there is some direct harvesting of a living, reef-attached, non-native and evassive kelp species (*Undaria pinnatifida*) in Tasmania. Only a single land-based macroalgal culture farm exists, at Shoalhaven, New South Wales growing the green algae *Ulva spp*. to sell as a protein meal and as a number of cosmeceuticals. While some macroalgae are harvested from the beaches in South Australia, the only culture undertaken has been at a research scale, with this focused on *Ulva spp.* and *Gracilaria spp. (a red algae)*, both farmed overseas and suitable for a range of products, including abalone feed and human food. *Gracilaria* is also used widely for production of agar, a gelling compound. Both *Gracilaria* and *Ulva* are marine species and will grow in temperatures of 10-40°C and salinities of 5-40 ppt, but both typically prefers temperatures of 20-30°C and salinities of 15-25 ppt (*Gracilaria*) and 30 ppt (*Ulva*).	e.g. Nayar et al. (2015), Roos et al. (2019)
Microalgae	Occuring NT, SA and WA.	Only two types of microalgae are presently farmed on a large scale in Australia, the green alga *Dunaliella salina* and the blue-green alga *Spirulina spp*., although many more are in other part of the world. Both are primarily marketed as human health products.	As suitable references are species specific none are provided here

				In South Australia, *Dunaliella salina* is produced in a few very large shallow ponds using saltwater and added nutrients; *Spirulina* is produced in multiple, shallow smaller 50 m x 20 m ponds on a farm near Darwin. *Dunaliella salina* is typically grown in temperatures of 12-35°C and salinities of greater than 200 ppt (controls competitors and grazers). *Spirulina* is typically grown in freshwater at a salinity of about 30 ppt.	
Mulloway	*Argyrosomus japonicus*	Occurring NSW, occurred in past in SA.	Hatchery – partial RAS Growout – ponds; stopped in sea cages	A hardy coastal estuarine and marine Australian (Mulloway) and South African (Dusky Knob) temperate species with a wide salinity tolerance from near freshwater to marine (5-35 ppt), and a wide temperature tolerance of about 5-35°C. The species has a moderate growth rate from fingerling (20-30 g) to market size (1.5 kg), which is achieved in 14-20 months. The species is ideal for culture in ponds and tanks due to its docile nature and less aggressive feeding behavior. Hatchery and growout methodologies are well known and relatively simple. However, there is a need to grade fish frequently when small to reduce cannibalism. Mulloway grow well between 21-26°C and 18-38 ppt, and best at 25-26°C and 18 ppt. Growth slows at <18°C and above >28°C, feeding is low and fish stressed at <14°C and >30°C, with mortalities increasing at <12°C. In the Sydney area Mulloway grown in sea cages reached 1.1 kg and 45 cm length within 26 months; in tanks at an optimal temperature they grew to 2 kg and 60 cm length in 24 months. Juvenile and adult Mulloway, respectively, tolerate <4.3 and <6.8 mg L^{-1} TAN, 0.24 and 1.04 mg NH3-N L^{-1}, and pH of 8.8 and 9.6. The lethal limit of dissolved oxygen is <1.70 mg L^{-1}. At about 18-19 ppt, Mulloway grown in inland saline groundwater have been found to need potassium levels of >83 mg L^{-1}; some saline groundwaters can be deficient in potassium. Stock densities just prior to harvest of 15-50 kgm^{-3} have been reported from sea cage, pond and tank systems. A commercial aquaculture venture in NSW has produced about 100 tonnes of mulloway annually from about 11 ha of ponds (mostly 0.9 ha in size). FCRs have been reported between 1:1.2 to 1:2.7. Considered by many as an ideal inland aquaculture species because of its broad tolerance to salinity, particularly if it can be cultured at a constant mid-20°C temperature. A constant 24-25°C temperature will achieve a time to market about	e.g. Hutchinson and Flowers (2008), Fielder and Heasman (2011), Guy and Cowan (2012), Kruzic et al. (2016)

				30% faster than when the species is grown in sea cages with a seasonal temperature pattern of 12-24°C. Meagre (*Argyrosomus regius*) and Red Drum (*Sciaenops ocellatus*), both species related to Mulloway, have been farmed in Europe and the USA, respectively, with most farming occurring in ponds, but some in cages in the sea. These species are considered good candidates for farming because of their biological and marketing characteristics, except for their lower price, which has however increased as wild fisheries volumes have declined due to overfishing and population related impacts on estuaries.	
Murray Cod	*Maccullochella peeli*	Occurring SA, VIC, NSW and QLD	Hatchery – partial RAS Growout – ponds, RAS, tanks	A hardy, temperate Australian freshwater species that grows to a large size (up to 2 m and 113 kg in the wild), breeds easily, grows rapidly (2-600 g in 6-14 months and 0.6-1.3 kg in 10-18 months at 20-25°C), is regularly graded in the early life cycle stages to manage aggression and cannibalism, is adaptable to crowning (cultured in RAS at 40-100 kg m^{-3}) and is hardy. One challenge is that broodstock lay eggs in nests in ponds, this stage requiring low stocking rates and ponds. Thereafter culture can be done intensively. Like most native freshwater finfish species, general water quality characteristics are: pH 6-8, dissolved oxygen >3 mg L^{-1} and free ammonia <0.1 mg L^{-1}. FCR for RAS farmed fish are typically in the range of 1.5-2.1. Hatchery and growout methodologies are well known, although not well disseminated, particularly for RAS systems. A number of commercial operations have been in existence for more than a decade, and while some have failed a number have recently been expanding from 50-300 tonnes per annum to target in excess of 1,000 tonnes. Larger commercial farms tend to be a combination of RAS and pond culture (i.e. fish grown to 100 g in RAS and then stocked into cages in ponds), with a general trend towards further intensification. A number of the larger farms are aligned with Murray-Darling River irrigation enterprises, using the fish farming wastewater for agriculture (e.g. citrus). Fisheries Victoria has worked with the industry to facilitate selective breeding, which is leading to further increases in production. The species is sometimes farmed in aquaponics systems.	e.g. Ingram and De Silva (2004); Lennard (2005), NSW Department of Primary Industries (2016d), Victorian Fisheries Authority (2017b)
Oysters	*Crassostrea gigas*	Pacific Oyster: Occurring	Hatchery – partial RAS.	Pacific Oysters are farmed in many countries whereas the Native Oyster is endemic to Australia. Both are cool and warm temperate estuarine and coastal marine species grown in-sea using naturally available feeds. Pacific Oysters are usually grown intertidally in baskets on longlines stretched between posts, whereas Native	e.g. Grove-Jones (1986)

	Ostrea angasii *Saccostrea glomerata*	SA, TAS, NSW & QLD. Native Oyster: Occurring SA, VIC & NSW. Sydney Rock Oyster: Occurring WA, NSW & QLD; attempted a number of times in the past in SA but has not been successful.	Growout - in-sea using naturally available feeds, just subtidally on racks and in baskets on longlines.	Oysters are grown the same way but subtidally. Sydney Rock Oysters are often grown intertidally in racks in NSW. Overseas Pacific Oysters are often grown subtidally in barrels hanging from longlines or hanging on lines from floating rafts. The Pacific Oyster is typically the fastest growing and hardiest of the three species reaching market size of about 70-80 g in 12-18 months, although Pacific Oyster Mortality Syndrome (POMS) has relatively recently caused major mortality events in NSW and TAS, and more recently been detected in the Port River estuary in South Australia. Native Oysters (farmed on a small scale in South Australia) and Sydney Rock Oysters (past culture attempts in South Australia have failed) are also susceptible to a range of diseases, the former bonamiosis in particular. Oysters typically have an optimum temperature range for growth of about 10-28°C and a wide salinity tolerance of 20-45 ppt, although larvae prefer 25-32 ppt. Hatchery and growout methodologies for Pacific Oysters and Sydney Rock Oysters are well known, but less so for Native Oysters. Normal oyster growout is not recommended for land-based aquaculture due to the higher costs associated with such methodology, although specialised short-term nursery and 'product finishing' in ponds (e.g. France) occurs in some parts of the world and might prove feasible in certain situations in South Australia. While Pacific Oyster culture in South Australia first occurred in one of the Dry Creek Salt Field Ponds just to the south of 2W2W, this is not recommended for the future unless in an IMTA system, where the oysters were used to remove particulate organic matter.	
Octopus	*Octopus tetricus*	R&D, but not started.	Hatchery - partial RAS Ranching techniques – wild capture and farmed in land-based tanks or in-sea 'cages'	A warm temperate Australian marine species believed to have aquaculture potential based on market price and an achieved rapid time to market size of 800 g in 18 weeks. The R&D associated with the ranching of juvenile octopus in tanks without hides at 16-23°C, 35 ppt, >4.5 mg L^{-1} dissolved oxygen and a flow rate of 100 L kg^{-1} $octopus^{-1}$ hr^{-1} has demonstrated promise, with a maximum stock biomass of 54 kg m^{-3} of 50 g individuals achieved. However while octopus paralarvae could be produced in large numbers their growth and survival was poor, limiting commercialization. In-sea aquaculture R&D has also not yet been very successful. Not recommended for land-based aquaculture in the 2W2W as the species requires further research and development.	e.g. Kolkouski et al. (2015a), Kolkouski et al. (2015b)
Salmonids Rainbow Trout		Occurring	Hatchery – partial RAS	Salmonids are able to live in fresh to seawater (0-35 ppt), with Brown and Rainbow Trout typically farmed for their whole life cycle in freshwater, whereas Atlantic Salmon are bred in freshwater and then at the smolt stage transferred to seawater.	e.g. Hortle (1981), Molony (2001), pers. comm. Atlantic Salmon farm representatives (2016)

Ocean Trout Brown Trout Atlantic Salmon	*Oncorhynchus mykiss* As above *Salmo trutta* *Salmo salar*	Trout in WA, SA, VIC, TAS and NSW. Salmon, primarily in TAS.	Growout – ponds, tanks, RAS, stocking natural waterways	Salmonids are cool temperate species growing at temperatures typically of 4-19°C for Brown Trout and 10-20°C for Rainbow Trout. For Rainbow Trout temperatures from 18-24°C cause increasing stress leading to poor growth and then mortalities, with the latter common by 26°C Spawning and egg production for Brown Trout is at 6-10°C and Rainbow Trout at 9-14°C, which is why most trout operations in South Australia import fertilised eggs from Tasmania. Egg hatching water needs to be well oxygenated (>5-6 mg L^{-1} and silt free). Ocean trout are Rainbow Trout that are typically grown in freshwater to 70-100 g fingerlings when they are gradually acclimitised to seawater (smolt stage), in which they are then grown in cages. Trout grow rapidly and can weigh 800-1,000 g in 12 months, 2 kg in 2 years and 3 kg in 3 years under favourable conditions (e.g. water temperatures of 15°C). Trout aquaculture techniques are well known and documented, with trout farming most prevalent in Tasmania, and the cooler areas of Victoria and New South Wales. Trout farming in farm ponds also occurs in south-western Western Australia. Two pond based 'put and take' trout farms existed in the Adelaide Hills in South Australia, regularly experiencing summer mortalities before closing. Another put-and take' farm existed for many years near Mount Compass and a trout farm at Millicent, but these have also closed. A trout hatchery/nursery (eggs are typically imported from interstate) continues to be operated by the South Australian Fly Fishers Association in the Adelaide Hills for stocking of select government approved streams for recreational fishing purposes and a successful land-based Ocean Trout partial RAS facility exists near Beachport, South Australia. Trout, typically Rainbow Trout, are commonly farmed in aquaponics systems with cooler water (e.g. other than summer). Atlantic Salmon farming, Australia's most valuable aquaculture seafood industry, is primarily in Tasmania due to this State's cooler seawater temperatures (e.g. 9-18°C), where Atlantic Salmon hatchery and nursery stages are reared onshore in freshwater RAS, before being transferred to the sea where they are farmed in cages. The recent trend has been for holding smolt for longer (21 as compared to 18 months) onshore in larger and more comprehensive RAS before transferring them to sea at a larger size (i.e. 500 rather than 200 g). In sea cages Atlantic Salmon reach about 4.5 kg in another 14-18 months. Overseas RAS are increasingly being used for farming Atlantic Salmon to market size, with the production size of these RAS systems continuing to grow.

				Atlantic Salmon farming has been attempted in sea cages in the southern coastal waters of Western Australia, South Australia and Victoria but was unsuccessful primarily due to summer temperatures being too warm. Summer water temperatures have also been recoded as increasing in parts of TasmaniaS due to climate change, potentially increasing the risks to this industry.	
Sea Cucumbers	*e.g. Australostichopus mollis*	Not started, but a tropical species, *Holothuria scabra*, is produced in hatcheries and restocked in coastal waters in the NT.	Hatchery & nursery – partial RAS Growout - pump ashore land-based tanks and raceways, but most commonly ponds (in China) or mesh cages on the seafloor Stock enhancement – in shallow coastal areas	The Brown Sea Cucumber (*Australostichopus mollis*) is the preferred temperate species and the Tropical Sandfish (*Holothuria scabra*) *the* preferred tropical species. Adult Brown Sea Cucumbers are held in a hatchery and the separate male and female individuals release the eggs and sperm triggered through environmental manipulation. The fertilized egg, when it hatches, results in tiny planktonic larva, which are held in tanks with the 1st stage fed on mixed microalgae. The 2nd stage does not feed, with settlement onto the substrate occurring about 25 days after fertilisation. Once on the substrate they develop into juvenile adults and feed on organically enriched sediment. Growout is undertaken either in tanks, ponds, sea cages, or released free in the sea. The Brown Sea Cucumber has optimum growth and FCR at around 14-15°C, with little survival at 10°C and 24°C. Salinities of 34 ppt are optimal, with 28 ppt resulting in high mortalities after 5 days. The pH should be oceanic and not <7.9. Under good conditions the juveniles can grow to a size of 300 g and 25 cm in length in one year, but more typically in two. The wild-caught fishery for seas cucumbers in most countries is severely depleted. Possible as a component of IMTA in marinefinfish ponds in the 2W2W, but unlikely based on the cooler water temperatures and ocean salinities required.	e.g. Zamora and Jeffs (2011), Zamora and Jeffs (2012), Zamora (2014), Heath et al. (2015)
Sea Urchins	*e.g. Heliocidaris erthrogramma*	R&D in TAS (large scale R&D and small scale commercial evaluations in Norway).	Hatchery & nursery – partial RAS Ranching – typically in sea cages or stacked crates that can be raised and lowered from the seafloor to the surface	The endemic Purple Sea Urchin (*Heliocidaris erthrogramma*) is the most common sea urchin found in southern Australian marine waters, where it is commercially harvested from the wild in South Australia, Tasmania and Victoria. *Centrostephanus rodgersii* and *Heliocidaris tuberculata* are also harvested in New South Wales and eastern Victoria. Sea urchin ranching, the recent focus of most attention, is based on collecting sea urchins from the wild (often sea urchin barrens where large aggregations of sea urchins have depleted kelp forests) and conditioning them for 3-4 months by holding them and feeding a specially formulated manufactured diet (still under development) so as to enhance the weight and quality of their gonads. Growout can be undertaken in tanks, sea cages, or specially designed stackable mesh crates lowered to the seafloor and lifted to the surface each time feed needs to be added.	e.g. DEH (2005), Barker (2015), James et al. (2017)

			but also release to their natural environment	The specific environmental tolerances of the local sea urchin species are poorly known, but would be expected to match with the characteristics of cool – warm temperate oceanic waters of southern Australia. Sea urchins propagation has also been achieved and is seen as the long term solution to providing stock for aquaculture. Typically the larval phase, which is fed mixed microalgae, will be about 21 days, the nursery phase where they feed on diatoms on plates about 2-6 months and growout from a teste diameter of about 5 mm to 50-70 mm about 2 years. The wild-caught fishery for seas urchins in most countries is severely depleted. Possible as a component of IMTA in marine finfish ponds in the 2W2W, but unlikely based on the cooler water temperatures and ocean salinities required.	
Silver Perch	*Bidyanus bidyanus*	Occurring SA, VIC, NSW and QLD.	Hatchery – partial RAS Growout – ponds, tanks, RAS, stocking natural waterways	A hardy warm Australian temperate to subtropical freshwater omnivorous species typically farmed in ponds in subtropical areas (e.g. cotton irrigation ponds in Queensland) and occasionally in RAS in temperate areas (e.g. South Australia). Silver Perch tolerate <15 ppt, but optimum growth is between 20-30°C and at < 5ppt; there is negligible growth at <12°C. Spawning is hormone induced and typically at about 25°C. Like most native Australian finfish species, pH should be maintained between 6.5-9.0 (6-10), dissolved oxygen >4 mg L^{-1} and ammonia <0.1 mg L^{-1} (lethal at 0.6 mg L^{-1}). Hatchery and growout methodologies are well known. In Queensland, well managed pond systems, using drainable ponds of 0.1-0.5 ha in size and depths of 0.7-2.5 m, can achieve 5-10 tonnes ha^{-1}. Female silver perch produce about 125,000 eggs per kilogram of body weight and eggs hatch in about 36 hr. 1st feed larvae are about 5 mm in length after 5 days at 25°C and are reared in ponds fertilized to enhance the zooplankton (rotifers and copepods). Survival rates of >30% are possible between the metamorphosis and 15 mm fingerling stages, which takes about three - four weeks. The fingerlings then take five to seven weeks to grow to 30-50 mm when the hatcheries sell them to farmers for ongrowing. Based on on-line hatchery price information, Silver Perch fingerlings tend to be of similar price to Jade Perch and Golden Perch fingerlings, with price decreasing with the number purchased and increasing with size (but as an example $1.80 per 45 mm weaned fingerling for a batch of 100). Ongrowing ponds are stocked at about 20,000-100,000 fish ha^{-1}. After 9 months they may be counted and graded from nursery ponds and restocked in growout ponds at	e.g. Queensland Government (2018c)

				5,000-21,000 fish ha^{-1}. The fish are omnivore but are fed on pellets developed for native finfish species. FCR are about 1.2:1 for fingerlings and 1.5:1 for growout in ponds. Ponds are netted or 'wired' to prevent bird predation. Fish are harvested at about 400-600 g and purged for about 5-10 days in slightly salted water to remove off-flavours. Silver Perch have been farmed in aquaponics systems in temperate climates, but are not as fast growing as Jade Perch and Murray Cod.	
Snapper	*Pagrus auratus*	Stopped. SA & NSW in the past.	Hatchery – partial RAS Growout – primarily in sea cages	A hardy coastal marine temperate species occurring naturally in a number of countries, including Australia and New Zealand. Growth rate is optimal at about 23-24°C. Growth and feeding largely stop at 15°C and stress related mortalities becoming common at about 11°C. Growth rate is slower than Mulloway, which is slower than Yellowtail Kingfish. Salinities between 16 - 48 ppt are suitable for good growth; from 48 to 52 ppt growth and survival rapidly declined. When grown in inland saline groundwaters, the species has been found to be sensitive to low potassium levels, with a need for these to be >60% of the normal level in seawater (i.e. 380 mg L^{-1}) and with a K^+:Cl^- ratio of >0.007 for survival and >0.01 for good growth. Hatchery and growout methodologies are well known and similar to most readily bred and reared coastal marine finfish species; easier than Yellowtail Kingfish. A market size of 400-500 g was achieved in 12 months by pre-growing juveniles in the warmer waters of the cooling water discharge from a power station at Port Augusta (18.2-31°C, 43-48 ppt) as compared to 16-20 months in the open waters of Spencer Gulf (12-24°C, 37.5-38.5 ppt). Fish of a market size of 400 g and 28 cm length were grown in tanks and sea cages within 21 months in the Sydney area, the sea cages being initially stocked with fish of 30-50 mm length. Farming stopped primarily due to the species slow growth rate. Not recommended for land-based aquaculture in the 2W2W as faster growing finfish species exist.	e.g. Hutchinson et al. (1997), Partridge et al. (2003), Booth (2005)
Southern Bluefin Tuna (SBT)	*Thunnus maccoyii*	Occurring SA.	Hatchery – (R&D only & now stopped)	A tropical (broodstock to larvae) to warm temperate (juveniles - adults) pelagic species that circumvents the southern oceans and grows rapidly (e.g. from 15 to 35 kg in about six months in South Australia in sea cages at 12-23°C and 36-38 ppt). To maintain good growth the species needs well oxygenated water (<5-6 mg L^{-1}),	e.g. Ellis et al. (2009), Bubner (2011), Chen (2014)

			Ranching – sea cages	and in sea cages, water depths of >20 m and with reasonable currents to disperse and dilute wastes. Broodstock, hatchery and nursery methodologies have been developed in an onshore RAS in South Australia, but are not presently commercially viable. Stock continue to be sourced from the wild, with ranching sites ideally as close as possible to wild stocks. Growout methodology in sea cages is well established. Overseas, onshore RAS systems are being considered for the culture of Atlantic Bluefin Tuna. A combined pilot onshore and sea-based farming operation is proposed for the Canary Islands in 2019, but in Norway the intended site for commercial production of 12-30 kg fish is a land-based RAS. Not recommended for land-based aquaculture in the 2W2W due to the R&D stage of propagation and growout in RAS, and the availability of lower cost sea cage production areas offshore of Port Lincoln, South Australia.	
Southern Rock Lobster Tropical Rock Lobster Western Australian Lobster	*Jasus edwardsii* *Panulirus ornatus* *Panulirus cygnus*	Not started, R&D. TAS.	Hatchery – partial RAS Growout – raceways/tanks, sea cages	Southern Rock Lobster are a cool temperate marine species of rocky wave swept coastlines, including in South Australia, and are higher priced than Western Australian or Tropical Rock Lobsters. However, they have a more complex life history than these other species, comprising 13 life stages over 18 months in the wild, and are slower growing. Ongrowing of the small Southern Rock Lobster puerulus life stage to about a 200 g market size has been demonstrated to be feasible, but not commercialised primarily because of limited access to stock but also cost effective growout infrastructure and feeding. Water temperatures of 18, 20 and 22°C are reported to be suitable for growth, feeding and metabolism, whereas 24°C caused a decrease in performance and survival; the range 19-21°C was considered optimal. Salinities of 30 ppt and 35 ppt result in faster grow and lesser mortalities than 25 ppt or fluctuating salinity between 25-35 ppt. In South Australia legal size Southern Rock Lobster were ongrown commercially in sea cages so that they could be sold out of wild catch season when market prices were higher. This price differentiation disappeared after a few years so this ongrowing practice ceased. Research undertaken in TAS has closed the life cycle of the Southern Rock Lobster and greatly decreased the length of the time from egg to puerulus; with much of this information comprising valuable intellectual property and as such not disseminated.	e.g. Thomas et al. (2000), Bryars and Geddes (2005), James (2007), Jeffs and Hooker (2007), Simon (2009), University of Tasmania 2017

				Commercialisation of the process is still considered many years away, with most of the present research focused on the easier Tropical Lobster, which is already ongrown in Asia. The Southern Rock Lobster is not recommended for land-based aquaculture in the 2W2W or elsewhere as the species requires further work prior to commercialisation.	
Striped Trumpeter	*Latris lineata*	Not started. TAS.	Hatchery – partial RAS Growout – tanks, sea cages	A cool temperate Australian marine pelagic species, with its aquaculture potential well researched in TAS, where for many years it was considered the best native marine finfish species for diversification for the salmon aquaculture industry. Hatchery, nursery and growout methodologies are known known at a demonstration – pilot commercial-scale. Optimum temperature for rearing larvae was found to be 14-16°C and growout was successful at a site with an annual range of 9-19°C. Oceanic salinities were considered most suitable, but lesser coastal salinities, primarily in winter, were tolerated. Some 14 years of research that encompassed broodstock conditioning to growout in sea cages identified a wide range of challenges affecting the species growth & survival, including a long larval stage that required oceanic-like environmental conditions that were difficult to duplicate, and relatively slow growth rates and often significant mortalities throughout the species life cycle. The research addressed most of the issues that arose, but a basic economic analysis suggested it would take 14 years for an enterprise to reach 5,000 tonnes production and be profitable, a time considered too long for commercial success. A modelled growth projection suggested that fish put into sea cages at 104 g at one year of age should be able to achieve a weight of 1.6 kg within another two years, and possibly at a higher temperature, might achieve 2.1-2.8 kg.	e.g. Battaglene and Cobcroft (2010)
Sturgeon Beluga Sturgeon, Russian Sturgeon, Siberian Sturgeon and the Russian – Siberian	*Huso huso*, *Acipenser gueldenstaedtii*, *Acipenser baeri* and the *Acipenser gueldenstaed* x , *Acipenser aeri* hybrid.	Not started, but various species aquaculture d in Europe and the USA	Hatchery – partial RAS Growout – primarily intensive RAS	Sturgeon species occur naturally in parts of Asia, Europe and the USA, but not Australia. The Beluga naturally inhabits waters with a temperature range of 10-20°C and salinity range of 5.5-14.5 ppt, but can tolerate 2-25°C in seawater. Sexual maturity is reached at 10-16 years for males and 14-20 years for females; with spawning every 3-4 years. Natural maturation and early life stage development generally occurs, respectively, between 6-7°C and <21°C. Females swim from the sea to rivers to spawn, producing near the gravelly river bottom about 700,000 eggs over a couple of spawning events; they do not build nests.	e.g. Bronzi et al. (2011), Chebanov and Galich (2013), Maslyuk and Didenko (2013)

Sturgeon hybrid.				The Russian and Siberian Sturgeon occupy a similar habitat to the Beluga; although the Siberian Sturgeon inhabits rivers and estuaries and does not go into seawaters. Male Russian Sturgeon become sexually mature at 11-13 years and females at 12-16 years, about the same as the Lena River population of the Siberian Sturgeon (other populations take much longer). In aquaculture, the Russian–Siberian hybrid becomes sexually mature at 3-4 years for males and 4-5 years for females. Russian Sturgeon males reproduce every 2-3 years and females every 4-6 years; Siberian Sturgeon males every 2-3 years and females every 3-5 years. The Russian Sturgeon spawns in natural environments at 9-12°C and the Siberian Sturgeon at 9-18°C. Stocking densities of broodstock Beluga are 25-30 kg m^{-3} and Russian Sturgeon 20-25 kg m^{-3}. Sturgeon aquaculture requires cool freshwater, which while not identified in the 2W2W might be found at shallower depths in adequate supply for a RAS facility. However, other areas of South Australia, such as in the south-east of the State, are likely to be more suitable. The main challenge with sturgeon aquaculture will be the long lead time required. While federal government approval has been obtained for importation of stock, appropriate translocation and holding biosecurity protocols need to be developed and approved, imported eggs or juvenile stages reared to reproductive age, these fish bred and then the resultant progeny used for initiating aquaculture. This and development of the relevant facilities may well take a decade, as such sturgeon aquaculture in the 2W2W does not offer a significant short term opportunity.	
Turbot	*Scophthalmus maximus*	Occurring France, Portugal, Spain, Chile and China.	Hatchery – partial RAS Growout – tanks, both flow-through and RAS	A European cool temperate bottom dwelling marine species that grows rapidly and to a large size for a flat fish; it does not occur in Australia. The larvae are free swimming, planktonic and normally orientated, only becoming bottom dwelling and flat at metamorphosis at about 14-25 days post hatch. The species tolerance range is about 1-30°C and 12-40 ppt, with growth occurring at 8-22°C. Optimal growth is at about 18°C in the nursery and 14-16°C for growout, both at about 18 ppt. Stocking rates just before harvest are typically about 50 kg m^{-2}, although if shelves are used within the holding tanks 100 kg m^{-3} is achievable. The species feeds readily on pellets, FCRs are about 1-2:1 dependent on life stage. FCR is optimal at about 1:1.8 at 18°C and 15-19 ppt.	e.g. Seafish and Epsilon (2002)

				Market size is about 1-2 kg, with the species growing to about 2 kg in 24 months at seasonally varying sea temperature and faster at a uniform optimal temperature in RAS. Turbot have a very poor flesh recovery rate, fillets being about 30% of a whole gilled and gutted fish. Turbot farming in Australia would require a long lead time while approval was sought from federal and state governments to introduce a non-endemic species. Cooler groundwater would also need to be sought, with cooling likely to be needed for at least part of the year. Not recommended for land-based aquaculture in the 2W2W as it does not offer a short-term opportunity.	
Western Australian Dhufish	*Glaucosoma hebraicum*	Not started.	Nursery – RAS Growout – tanks	A warm temperate relatively slow growing Australian marine species that reaches a large size. A five-year research program in WA identified that spawning needed to always be induced and eggs stripped, larvae were difficult to grow and needed to be fed copepods additional to normal larval live feeds (rotifer and brine shrimp), and that numerous parasites and pathogens were common. The species is relatively sedentary, naturally occurring in oceanic waters of 15-26°C. Its optima for growth are: 17-22°C, 33-35 ppt and a pH of 8.1-8.2. The species is considered sensitive to poor water quality. The species accepts pelleted feed in culture but is a slow feeder; the larvae were found challenging to wean onto a manufactured diet. The fastest growing cohort of Dhufish durng R&D took about 13-14 months to grow to 280 g at 22.4°C and with a very low stocking rate of 1.3-1.8 kg m^{-3}. In the wild the species reach 27 g and 100 mm in about 12 months and is slow growing.	e.g. Cleary and Jenkins (2003)
Western King Prawn Other Australian prawn species	*Melicertus latisulcatus* *e.g. Penaeus monodon*	Stopped, SA. Occurring NT, QLD and NSW.	Hatchery – partial RAS Growout – ponds, intensive RAS have been used overseas (France,	In Australia, prawn farming generally refers to the farming of marine or brackish water species (often termed shrimp in other countries) as opposed to fresh water 'prawns'. Prawn farming is carried out in earthen ponds filled with seawater and aerated to supply oxygen and maintain the good water quality needed for optimal growth. The prawns are manually fed with specially formulated, pelleted feeds. The juvenile prawns used to stock ponds are sourced from purpose-built hatcheries. These hatcheries provide the conditions necessary for the mature broodstock to produce the eggs that will grow to be juvenile prawns.	e.g. Wu (1990), Hutchinson and Skordas (2014)

			Taiwan and USA)	Western King Prawn in South Australia are at their southern-most latitude with the wild fishery in 12-24°C waters. Aquaculture research has identified that the survival of smaller and larger juvenile prawns was suboptimal in saline groundwater of 14-16 ppt compared to seawater of 36-37 ppt, and that survival and growth could be improved by fortifying the groundwater with potassium. With white spot detected in QLD in 2017 translocation of tropical prawn species into South Australia is unlikely to obtain State Government approval at this time. Western King Prawn are not considered suitable for pond culture in the 2W2W because of their slow growth in temperate regions and the challenges of harvesting a prawn that buries in the sediment for much of the day. Intensive RAS would be feasible but viruses have been a problem in such systems in many countries.	
Yellowtail Kingfish	*Seriola lalandi*	Occurring WA, SA and NSW.	Nursery – RAS Growout – cages (overseas RAS)	An endemic coastal pelagic marine finfish species that occurs in many countries. In South Australia they are farmed in sea cages at 10-24°C (winter-summer mean maxima respectively), with good growth occurring at 18-25°C. In Western Australia (Geraldton) and New South Wales (Port Stephens) growth is faster, a result of the warmer seawater temperatures. In South Australia, 24°C was found to be optimal for growth of Yellowtail Kingfish as compared to 21°C and 27°C. In New South Wales, 22.7-26.5°C has been determined to be optimal for growth. At 20°C and 24°C, fingerlings and juveniles were increasingly affected by salinities of >41 ppt, with 45 ppt close to the species tolerance level. This is particularly relevant to farming in the upper gulfs regions of the 2W2W where temperatures can be >25°C and salinities >42 ppt. In Western Australia, Yellowtail Kingfish take about 2-3 months to grow to 25-50 g and about 15 months to grow to 4 kg in sea cages. In Port Lincoln, South Australia they take about 80 days under controlled environment hatchery – nursery conditions to reach 20 g and 80-100 mm in length, and then 12-18 months in sea cages at ambient water temperature to grow to 1-1.5 kg or 24-36 months to grow to 4-4.5 kg. These growth rates exceed those of Mulloway (~400g in 14-16 months), Snapper (~400 g in 16-20 months) and King George Whiting (~170 g in 24-30 months). Sea cage stocking densities used are about 15-20 kg m^{-3} and about 50 kg m^{-3} in RAS. FCRs for pellet feeds are about 1.8-2.2:6, with the better FCR achieved for smaller fish and RAS. Dissolved oxygen levels in RAS should be maintained as close to saturation level as possible. Yellowtail Kingfish and related species have long been farmed in sea cages in Japan and more recently in Chile, Ecuador, Mexico, USA and Europe. RAS culture has been	e.g. Hutchinson and Flowers (2008), Fielder and Heasman (2011), Bowyer et al. (2012), Cobcroft (2012), Roberts et al. (2012), Stone et al. (2014), Orellana et al. (2014) **Error! Hyperlink reference not valid.**

considered in Chile and the first Yellowtail Kingfish RAS farm is now in operation in Europe (Zeeland, Netherlands) producing a high quality, organic product. A number of others are under development targeting final production levels of about 2,000 tonnes $annum^{-1}$.

Yellowtail Kingfish are considered a suitable species for land-based aquaculture in the 2W2W because hatchery production is achievable, they have a rapid growth rate to market size, because their optimal temperature and salinity can be achieved and maintained using groundwater fed intensive RAS, and because they have a higher market price and good markets exist nationally and internationally.

3.1.8. Recommended species

Commercial viability is generally demonstrated if a species has been farmed and product sold for some period (NSW Government 2009). As this project focused short-term opportunities, recommendations to start-up 'new' aquaculture species are considered unsuitable as an outcome for this project as the R&D phase associated with such an activity is likely to take in the order of 3-5 years and scale-up and commercialisation another 3-5 years. This timeline is likely to be even longer if the species are not endemic to the proposed area of culture or to Australia (e.g. sturgeon, which has been of interest to some South Australian aquaculture entrepreneurs), due to the necessity to seek relevant government importation, translocation, and aquaculture and development planning approvals; the species takes a considerable time to reach maturity and/or considerable R&D needs to be done to adapt overseas knowledge for the local environment.

The species considered to have the greatest commercial aquaculture potential within a reasonable time frame (3 years) in 2W2W are:

- the freshwater species, Murray Cod;
- the marine species, Yellowtail Kingfish; and
- estuarine species, Barramundi and Mulloway.

A number of other species have also been identified as potential candidates (e.g. Jade Perch and Silver Perch), but are less preferred as their marketing potential for establishment of a substantial industry is considered to be inferior to the species selected.

Murray Cod (freshwater species)

Murray Cod is an iconic, endemic Australian warm temperate freshwater species, having in the past been abundant in the Murray-Darling Basin and growing to a length of over 2 m, the largest of any Australian finfish species. However, over time the species has been overfished, commercial fisheries closed and recreational fishing closely managed and largely dependent on re-stocking programs. As such, the species has an identifiable market name but limited product is available, with this primarily from pond and tank aquaculture ventures in New South Wales and Victoria. At the time that data were sourced, the key marketer of live fish in South Australia (Mark Lee Fish Farm) was selling farmed Murray Cod from interstate at \$27.99 kg^{-1} (as compared to farmed Barramundi from South Australia at \$19.99 kg^{-1}).

Overseas, the species is identified as a 'Cod' and as such, relatively high price markets exist, especially in Asia.

Considerable knowledge exists on the culture of Murray Cod and the relevant information continues to grow and be disseminated. Over many years, Fisheries Victoria have done considerable research, which has been published (e.g. Ingram and De Silva 2004), on hatchery production, growout (in ponds, tanks and RAS), nutrition, selective breeding and marketing. Importantly it has been demonstrated that hatchery production is readily achievable; growth rate to market size is the best of Australian native freshwater finfish species with the fish having the potential to grow to a useful market size of 4 kg; there has been good consumer satisfaction with the product; market prices are relatively high; and markets exist nationally and internationally. Based on these characteristics a small commercial industry has developed in New South Wales and Victoria based on pond, tank and RAS operations, with some farms now having been in operation for 5-10 years. However, many operations are reported to have experienced start-up challenges and total Murray Cod production is still low. The commercial viability of some farms has also been questionable with some closing. However, from discussions with people with linkages to this industry sector, a positive outlook is said to exist with a number of farms scaling-up and a recent call for investment in a Victorian RAS based Murray Cod operation rapidly over subscribed.

While Murray Cod occur naturally in temperate environments, much faster growth can be obtained if a uniform mid-20s temperature can be maintained all year round. This and the limited rainfall, surface water sources and high evaporation rates in 2W2W indicates a RAS is to be preferred. Such a system, using freshwater (ideally less than < 5 ppt) as required by Murray Cod, will also provide benefits in that the wastes and wastewater can be effectively utilised for hydroponics, aquaponics or agriculture, offering the potential to increase farm income.

Yellowtail Kingfish (marine species)

Yellowtail Kingfish are a semi-tropical marine species occurring in such geographically separated locations as Australia, Central America and Japan. The main, but small, wild fishery in Australia is in New South Wales where most of the product is also sold (a very small seasonal fishery existed in South Australia many years ago, but more recently the focus has been as a recreational fishery). Only since aquaculture was initiated has product been more readily available on the domestic market, although much is marketed overseas particularly to Europe and the USA. At the time data were sourced, the small quantity sold on the wholesale market in Adelaide (SAFCOL) had a price of \$14.09 kg^{-1}, whereas on the retail market (IGA

Pasadena Supermarket) it was priced at \$21.77 kg^{-1} for whole fish and \$38.85 kg^{-1} for fillets; prices a little more than but not that different to Mulloway and Barramundi.

The level of knowledge on the aquaculture of Yellowtail Kingfish continues to grow and be disseminated. Over many years, there has been considered R&D undertaken on this species (e.g. Fielder and Heasman 2011, Bowyer et al. 2012, Cobcroft 2012, Roberts et al. 2012, Stone et al. 2014), including on hatchery production, diseases and pests, growout (in sea cages), nutrition, selective breeding and marketing. Importantly it has been demonstrated that hatchery production is readily achievable; growth rate to market size is the best of local native marine finfish species with the fish having the potential to grow to a large market size of 4.5 kg in 2-3 years; there is good consumer satisfaction with the product; market prices are relatively high; and proven markets exist nationally and internationally. A commercial aquaculture industry has existed in South Australia for more than 20 years, with new entrants developing their operations in New South Wales and Western Australia. All rely on land-based hatchery production and growout offshore in sea cages.

Yellowtail Kingfish growth, food conversion ratio and health is greatly affected by temperature. It is evident that much faster growth rates are achieved in waters with a higher ambient temperature, with the range experienced by present farms from 10-28°C. In winter, where temperatures decrease below 15°C Yellowtail Kingfish growth essentially stops. Yellowtail Kingfish survive and grow in salinities from about 18 ppt (Hutchinson and Flowers 2008) to 41-44 ppt (Stone et al. 2014), but a narrower range is recommended for optimal growth, feed intake and FCR (20-37 ppt).

Yellowtail Kingfish naturally occur in warm temperate to subtropical environments, with much faster growth if mid to upper 20°C temperatures can be maintained all year round as compared to natural South Australia gulf water temperatures that vary seasonally from 11-24°C. An intensive RAS, which have been developed for the farming of this species in Europe, would enable such temperatures to be achieved. Intake water would ideally come from a lower-central gulf location, to avoid the extremes of temperature and salinity that characterise the northern parts of the gulfs, where flat agriculture land with only a low pumping head (height above sea level) abuts the coast. Wastewater could potentially be used to grow macroalgae, which could be used to remove soluble nutrients prior to the discharge of the water back into the gulf and produce a saleable product.

Barramundi and Mulloway (estuarine species)

Barramundi, which occur naturally in tropical waters, and Mulloway, which occur naturally in warm temperate waters, are both hardy species that are readily produced in hatcheries, with larvae and juveniles able to be maintained at high densities if regularly graded to minimise cannibalism. They also have broad salinity tolerances, and do need seawater for their propagation and early life cycle phase, and both grow rapidly at their optimal temperature and to a large size if sufficient time is given, enabling them to be marketed at plate-size (400-800 g) or at a larger size for share, banquet or large fish or fillets (e.g. 2.0-3.0 kg). They are also used to produce a range of value-added products such as cold and hot smoked small whole fish and fillets, as well as dip/pâté. Australian Barramundi fry and fingerlings are also in high demand overseas.

Barramundi have been farmed in Asia and Australia for many decades, including onshore intensively in ponds, tanks and RAS, and in the sea in cages. A large commercially successful hatchery and growout farm using geothermal water exist in South Australia and a large RAS farm also using geothermal water in Victoria. Barramundi have also been produced in RAS in Europe and the USA, where the product has been well accepted domestically. The species is well known to consumers in Australia because of its reputation as an excellent recreational species; product from the wild has been marketed widely; and production from aquaculture and the wild is substantial. Australian product has proven domestic and international markets exist, although Australian domestic market prices have the potential to be negatively affected by cheaper imported Asian product. At the time data were sourced, the wholesale market price in South Australia (SAFCOL) for the small volume sold was \$11.58 kg^{-1}, whereas the retail market price (IGA Pasadena supermarket) was \$19.99 kg^{-1} for smaller whole farmed Barramundi and \$38.81 kg^{-1} for fillets, similar to those of Mulloway, but slightly less than those of Yellowtail Kingfish. Small Australian RAS producers have also been challenged in the past at times, by more cheaply produced Australian pond or sea cage cultured product or by off-flavours linked to some of the product produced from RAS (Jones et al. 2013, Hathurusingha and Davey 2014). Increasing the production scale of RAS has been widely predicted to lead to economies of scale and depuration of fish in clean water prior to marketing has been used successfully to prevent the marketing of product with off-flavours. Hathurusingha (2011) has suggested the low-level dosing of RAS with hydrogen peroxide as a biocide as an alternative method to managing off-flavours.

As Barramundi are a tropical species, water temperatures of 25-30°C are desirable for good growth. As such, aquaculture in 2W2W is only feasible in RAS and cost-effective ways of achieving such water temperatures need to be an important consideration. Just to the south of 2W2W in the Adelaide Plains Region is the T2 Aquifer, which has proven groundwater temperatures of 24-26°C at the surface and water quality that is satisfactory for the growout of Barramundi (as demonstrated by two existing Barramundi RAS, one a farm and the other a hatchery). Sources of waste heat from RAS equipment (e.g. blowers) can also be used to maintain water temperature and solar power supplementation can be used to offset electricity costs.

The Mulloway has a coastal and estuarine Indo-Pacific distribution and has been of interest for aquaculture since the late 1990s in Australia and South Africa. The closely related Meagre is also farmed in southern Europe (France, Italy and Spain), as is the more distantly related Red Drum in the USA (Texas). Aquaculture of all these species occurs primarily in ponds on land, with some in cages in the sea. The species are popular because of their ease of production in the hatchery, relatively rapid growth, hardiness during culture and marketability, because they are known from wild fisheries, and can be sold at plate size (600-800 g) or larger (2-3 kg) for fillets. At the time data was sourced, the wholesale market prices in South Australia (SAFCOL) for the small volume of Mulloway sold was \$9.90 kg^{-1}, whereas the retail market prices when product was available (IGA Pasadena Supermarket) was \$18.49 kg^{-1} for small whole fish and \$38.37 kg^{-1} for fillets, prices slightly lower than for Barramundi and Yellowtail Kingfish. While a good domestic market is considered to exist for Mulloway, the marketing of Australian Mulloway overseas is largely untested and considered to have less potential than the other species preferred for 2W2W, although the Mulloway farm in New South Wales indicated that plate-size fish at that time could be marketed in Asia at \$14.00 kg^{-1}.

Mulloway have a wide salinity and temperature tolerance with good growth from 18-38 ppt and 21-26°C, with 20-30 g fingerling in ponds under these conditions able to reach a market size of 1.5 kg in 14-20 months and 2 kg in about 24 months. The species docile nature and less aggressive feeding behavior makes it ideal for culture in ponds and tanks, where FCR are typically 1.2-2.7, with lower values achievable for smaller fish and optimised feeding practices and water temperature. Stock densities prior to harvest of 15-50 kg m^{-3} have been reported from sea cage, pond and tank systems.

While considerable R&D has been undertaken on Mulloway in Australia, only one commercial Mulloway aquaculture venture is known to exist at present in New South Wales, with this having a production of about 100 tonnes of Mulloway annually. A small number of other commercial pond and sea cage-based ventures have started in the past but since closed, with sea cage ventures typically changing to farming the faster growing Yellowtail Kingfish, which also has a more suitable behavior for sea cage culture. While

Mulloway has been advocated as an ideal species for inland saline groundwater aquaculture ventures by many researchers, no such ventures have yet been commercialized. This is believed to be more a function of the challenges of inland saline aquaculture than with the species.

Mulloway aquaculture in 2W2W is considered feasible in ponds in a number of areas, particularly those where pond-based ventures have occurred in the past (e.g. a prawn farm near Port Broughton and salt production near Dry Creek). Mulloway with their broad salinity and temperature tolerances already frequent these areas naturally and with appropriate management should tolerate the low winter and high summer water temperatures experienced. Initially caging the small fish when they are introduced to the ponds is a method that can be used to minimise bird predation. Mulloway farming in these areas may also provide opportunities to diversify an aquaculture business by integrating other forms of aquaculture to enhance sustainability, as well as offering recreational fishing and conservation-based tourism activities.

4. Site Selection

Selecting an appropriate site for an aquaculture operation is critical to a successful operation and many Australian state governments provide general advice on the matter and/or have relevant publications available, including specifically in relation to land-based aquaculture:

- New South Wales (NSW Department of Primary Industries 2016e**Error! Hyperlink reference not valid.**),
- Queensland (Queensland Government 2016),
- Victoria (Victorian Fisheries Authority 2017a**Error! Hyperlink reference not valid.**), and
- Western Australia (Department of Fisheries 2013)

In South Australia a number of key reviews relating to locations and species for aquaculture have been undertaken in the past (e.g. Far Northern Spencer Gulf, PIRSA 1998; Port Pirie, AGC 1998; SA, PIRSA 2001; and PPK 2002).

Key issues to consider when selecting a site for land-based aquaculture include climate, presence of necessary infrastructure, availability and nature of land, water supply and potential environmental impact.

4.1. Climate

The 2W2W area is characterised by mild winters and hot summers, with the climate described as 'temperate' south of a line between Wallaroo on the coast of Spencer Gulf to the west (160 km northwest of Adelaide) and Clare to the east (140 km north of Adelaide) and 'semi-arid' above this line. Coastal areas generally experience a milder and wetter climate than more inland areas (DEWNR 2013).

The Bureau of Meteorology and Weather Zone websites provides temperature, rainfall and evaporation statistics for the region. Average annual evaporation rates increase from south to north across the N&YNRMR, with the south experiencing around 1400 mm compared to 2600 mm in the north.

High summer temperatures, low rainfall and high evaporation rates mean that water replenishment of land-based extensive and semi-intensive aquaculture systems will need to be substantial to maintain water volume and prevent salinity increases, and shallow near-shore gulf waters will be highly saline. The large diurnal and seasonal temperature fluctuations will also greatly influence the performance of aquaculture species in shallow pond environments.

Indicative long-term average data representative of 2W2W (Weatherzone 2017) are:

Adelaide: Maximum monthly average temperature of 29.5°C in February; minimum monthly average temperature of 7.5°C in July; annual average rainfall 551 mm; 117 rain days; estimated annual potential evaporation of 1,900 mm.

Whyalla: Maximum monthly average temperature of 28.8°C in January; minimum monthly average temperature of 7.3°C in July; annual average rainfall 271 mm; 65 rain days; estimated annual potential evaporation of 2,400 mm.

The Goyder Institute for Water Research (2016b), in summarising past climate change predictions by CSIRO, highlighted that South Australia will experience increased temperature, reduced rainfall, increased rainfall variability, increased evaporation, increased drought, and increased frequency of extreme weather events, and that these are likely to result in a reduced supply from water resources.

4.2. Associated infrastructure and services

The terms 'Infrastructure' and 'Services' are used in this report to encompass requirements for communications (e.g. telephone and internet); effective transport of items to and from the site (e.g. aquaculture feed and product respectively) using for example road, rail and/or aeroplane; power supply (preferably 3-phase electrical supply) and aspects associated with access to trades people, and the capture and retention of a suitable labour force, for example, housing, potable water, sewerage, shopping, entertainment and even educational facilities for children. The availability and capacity to share infrastructure and services offers a major potential cost saving; and its absence does not necessarily preclude development as it can, at a price, generally be addressed in some manner.

A detailed presentation of the infrastructure within 2W2W is not provided in this report, although a brief overview of transport, power and aspects of land-use has been addressed ina range of broader regional reports by South Australian Government Departments, such as Department for Infrastructure and Transport.

4.2.1. Transport

Within 2W2W, infrastructure and services range from excellent within and adjacent to the main cities to entirely absent at a specific site away from any present form of human habitation. In general, 2W2W is well serviced because of the presence of the cities of Adelaide to the south and Port Pirie, Port Augusta and Whyalla to the north. The main national central northern highway and railway pass through 2W2W from Adelaide to Port Augusta, and secondary highways run nearly parallel to this further inland, with many interconnecting roads between. Port Augusta is also a focus of the east-west national railways and roads. Bowmans Intermodal, near Port Wakefield, is a transport hub and interconnector to Adelaide and the cities to the north. An international airport is present in Adelaide, good regional airports exist at Port Pirie, Port Augusta and Whyalla and 2W2W is well placed to access the developing Northern Adelaide Food Park.

4.2.2. Power

All but the most extensive aquaculture systems typically involve some form of water pumping and aeration to maintain the health of the cultured animals so need a source of power, which is also extremely useful for many other aquaculture operations. For security, aquaculturists typically require two forms of power, one as the principal source and the other for back-up if the principal source fails. Mains electrical supply generally provides the simplest and most cost-effective supply, with diesel generators used for back-up.

Mains electrical power coverage and supply in 2W2W are generally good within and between major cities and towns, but can be absent from specific sites, both on the coast and inland. Connection to mains power, where required, is an expensive undertaking for new aquaculture ventures even if new lines only have to be established over a few kilometres. As such, it is an important factor in site selection.

It should be noted that power supply in South Australia, as in many other places, is in the process of transitioning from a major reliance on coal fired power plants (the Northern Power Stations at Port Augusta have closed) to a much greater supply from renewable sources. South Australia’s present large (over 50%) and national leading use of power from renewables (wind and solar) along with a range of other factors (e.g. high-power usage during hot weather in summer) have caused some challenges that aquaculturists need to consider (reliability of supply and high cost). The South Australian Government has energy plans to address this situation in the short and medium term (e.g. ‘South Australia-New South Wales Electricity Interconnector’ and ‘South Australia’s Virtual Power Plant’ solar power household battery storage) with the federal government also putting in place changes to improve the situation.

4.2.3. Land-use

Agriculture

The predominant agricultural land uses across 2W2W are cropping and grazing (Figure 4.1a,b), with this region including some of South Australia's most productive and most costly farmland. Barley, wheat and oats are the principal focus of primary production with a small amount of horticulture in the south and around Baroota, just north of Port Pirie. Grain, livestock and food processing facilities servicing surrounding regions are also important.

Presently, horticulture dominates the NAP to the south of 2W2W, extending northwards to above the Gawler River. In the longer term, however, it is predicted that intensive agriculture of pork, poultry, beef and lamb may develop in 2W2W as far north as Port Wakefield on Gulf St Vincent across to the western edge of the Mount Lofty Ranges (Goyder Institute 2016a). Such growth of agriculture will require access to additional land, energy and water, with water in the NAP Prescribed Water Resources Area (PWRA) presently primarily from the T1 and T2 aquifers, and recycled water from the Bolivar Wastewater Treatment Plant (WWTP) distributed via the Virginia Pipeline Scheme (VPS). In the future (Goyder Institute 2016a), additional water for the NAP and southern 2W2W are likely to be increased through sources from:

- Recycled water: SA Water presently provides 19.5 GL of recycled water to the VPS, with an additional 20-22 GL potentially available. It does, however, have variable water quality, with data from 2011-15 indicating total dissolved solids of 856 – 1200 ppt, total nitrogen of 8.97-13.53 mg L^{-1}, total phosphorus of 1.36-3.53 mg L^{-1} and sodium of 241.5-329 mg L^{-1}, which is unsuitable for aquaculture purposes without treatment. The cost to access water is significant at $1,219.54 annually for up to 3 connections per customer, with water an additional charge of 8.13 cents KL^{-1} in winter to 15.4 cents KL^{-1} in summer (c.f. domestic water at 35 cents KL^{-1}). WWTP are derived from potable water from domestic, commercial and industrial use and as such has relatively low salinities, typically <1.0 ppt.
- Groundwater: Presently 27 GL is allocated for extraction from the T1 and T2 aquifers and this resource is considered to be over-allocated but not over-used. Potentially an additional 2-4 GL could be available within the PWRA, with a further 22 GL of higher salinity water available to the north of the PWRA.
- Natural watercourses and stormwater: The median harvestable volume has been estimated as 24 GL, including 10 GL from the Gawler River. Potentially another 5 GL $annum^{-1}$ of stormwater could be reliably harvested from Adelaide's northern urbanised catchments.
- Water use efficiency: a 10% water efficiency gain could make another 3 GL of water available.

- The Gawler River: The Gawler River Reuse Scheme aims to harvest 1.6 GL $annum^{-1}$ when operational. A total of 10 GL will be made available under the Western Mount Lofty Ranges Water Allocation Plan.

Figure 4.1a. General land-use within the Two Wells to Whyalla Regional Corridor from Port Broughton north to Port Augusta (source: PIRSA).

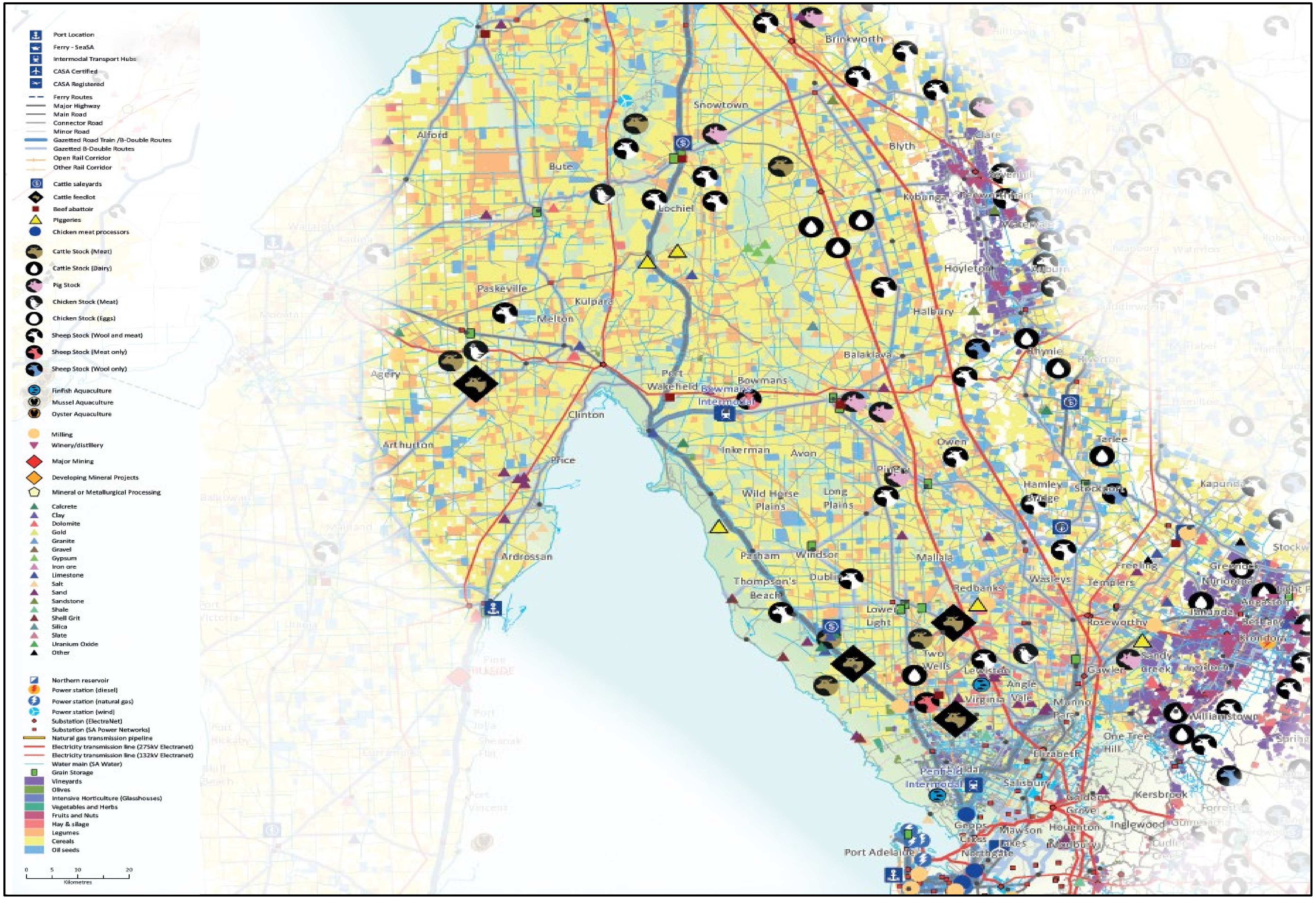

Figure 4.1b. General land-use within the Two Wells to Whyalla Regional Corridor from Two Wells north to Port Broughton (source: PIRSA).

Fishing

Commercial fishing is important in Gulf St Vincent and Spencer Gulf, with Western King Prawns, various species of marine finfish and Blue Swimmer Crabs. Commercial vessels are harboured at a number of locations, with the most important in 2W2W, Wallaroo and Port Pirie. Recreational fishing is a major attraction for locals and tourists with King George Whiting, Southern Garfish (*Hyporhamphus melanochir*), Snapper, Southern Squid/Calamari (*Sepioteuthis australis*) and Blue Swimmer Crab popular targets for fishers and Giant Cuttlefish (*Sepia apama*) for divers. Aquaculture developers need to consider the access rights of these user groups.

Minerals

Mining and mineral processing is important in 2W2W, with Port Augusta and Port Pirie both traditional mining towns. Port Augusta was a major service centre for Atlinta Energy's Leigh Creek coal mine, which has recently closed, and Port Pirie has the redeveloping Nyrstar lead smelter facility, which produces silver, zinc, copper and gold. The company is moving toward an advanced metal recovery and refining facility enabling the processing of a wider range of high margin materials. While working with the South Australian Government to reduce its environmental footprint, lead contamination is still a significant issue of the surrounding land and sea and needs to be considered when undertaking developments in the area (Gaylard 2014).

Whyalla has a fully integrated large steel production plant with inputs from South Australia and interstate, with finished steel products leaving by rail, road and sea. The business has recently been purchased by GFG Alliance. While Arrium, the previous owner, has worked with the South Australian Government to curtail 'iron' dust and nutrient enrichment in the area, its affects should be considered when undertaking developments in this area (Gaylard 2014).

Port Lowly, just north of Whyalla, is shared by a combination of defence, industrial, residential, recreational and tourism interests. This area and Port Bonython immediately to the north-west, are marked for future industrial expansion.

Power generation

Atlinta's coal-fired Playford and Northern Power Stations at Port Augusta have recently been decommissioned; with the surface of the adjacent land undergoing rehabilitation. Of particular interest to aquaculture developers in the past, were the inlet and outlet channels of the cooling water for the power stations. The key advantage was the high flow rate of both channels and the warm water discharged, which had the potential to greatly accelerate the growth of aquaculture species during the winter period. The disadvantages were the rapid and high levels of biofouling that developed on aquaculture structures in the warm water discharge channel and the concern about chemical pollutants (Gaylard 2014) associated with the operation of the power station (e.g. chlorine which was used for keep the cooling water pipes clean). Such pollutants had the potential to affect the performance and/or health of the aquacultured organisms and raise chemical residue levels in marketed product above acceptable levels (although this is not known to have ever happened).

Within 2W2W, a number of solar powered power generation systems are either under development or planned, and feasibility studies are also assessing the potential for pumped hydro energy systems.

Defence

The Australian Department of Defence's "Cultana Training Area", which comprises 2,093 km^2 of land adjacent to most of the western coast of Spencer Gulf between Point Lowley and Port Augusta, essentially prevents the use of this area for aquaculture development, although a narrow coastal strip is available for public use, with shacks existing in some places (Australian Government Department of Defence 2016). The Australian Government Department of Defence also has the "Port Wakefield Proof and Experimental Establishment", which occupies 56 km^2 of land and sea south of Port Wakefield along the eastern side of Gulf St Vincent, which restricts development in this area (Australian Government Department of Defence 2016).

Salt production

The Dry Creek salt fields stretch north of Port Adelaide from Dry Creek to St Kilda Beach then to Webb Beach at Port Paraham a distance of about 30 km along the coastline (Hough 2008). Production, which was focused on the manufacture of sodium carbonate and sodium bicarbonate, stopped with the closure of Penrice Soda in 2015. The salt ponds are now marked for housing development in the south, and elsewhere an international bird sanctuary, with some, adjacent to the northern pumping station and water inlet at Middle Beach, for other potential developments such as aquaculture.

Pacific Salt also has 2 km^2 of salt ponds adjacent to Whyalla and specialises in high quality table salt production (Evans 2017).

Coastal conservation areas and sensitive biological communities

Land-based aquaculture does not have to be dependent on land-based water resources; along the coast there is also the option to access seawater from piped water from offshore or a beach bore, and build relevant aquaculture infrastructure onshore adjacent to the coast. With this in mind, the following information is provided relevant to 2W2W, which is bordered in the south by Gulf St Vincent to the west and in the north by Spencer Gulf to the west between Wallaroo and Port Augusta and to the east between Port Augusta and Whyalla.

Relevant information has been sourced from published and unpublished reports, from satellite imagery on-line and a physical inspection of as much of the coastline as could be accessed from the land. Of particular relevance, is the wide range of information that exists to support past coastal zone planning and management associated with the development of the marine based aquaculture industry in South Australia, a task managed through PIRSA and that eventuates in the release of regional zone policy documents (i.e. PIRSA 2017c). These documents, in particular their supplementary background reports, typically identify locations potentially suitable for aquaculture development as well as locations where there should be no aquaculture development. This was done by considering a range of background physical and biological data. PPK (2002) is one such report that is unique in considering all the coastline of South Australia and presenting by geographical region, comprehensive information on climate, oceanography, water quality, geomorphology, biological environment, commercial fishing activity, existing aquaculture development, heritage sites, parks and reserves, demographics, land use planning opportunities and constraints, social environment and available infrastructure. This information has been supplemented by more recent publications such as Shepherd et al. (2008, 2014), which document the natural history of Gulf St Vincent and Spencer Gulf. On-line databases of the South Australian Department for Environment and Water (DEW) also provide a useful resource such as for marine parks (National Parks and Wildlife Service South Australia 2017) and biota and heritage information (Enviro Data SA 2018).

Gulf St Vincent

The Upper Gulf St Vincent Marine Park includes all the area north of a line about 3 km south of Middle Beach on its eastern side across the Gulf to Ardrossan on its western side. Within this area are three sanctuary zones (essentially non-use areas), one from about 1.5-10.5 km north of Middle Beach and extending 1.3-3 km offshore; one which includes nearly all the northern part of the Gulf from a line from about Port Wakefield on its eastern side across the Gulf to 2 km north of Port Clinton on its western side; one in the southern centre of the Upper Gulf St Vincent Marine Park, and one west of the Defence Prohibited Area, which runs north from Parham to just south of Sandy Point 10 km south of Port Wakefield and from the coast to about 6 km seaward.

A number of species of intertidal, supratidal and stranded salt marshes occur along the western margin of 2W2W, typically above mean high tide and in many places extending inland as far as 5 km, with the height range over this distance being as little as a 60 cm (Figure 4.2, Fotheringham and

Coleman 2008). Seaward of the salt marsh are mangroves (*Avicennia marina var. resinifera*), which occur primarily in the south from Port Adelaide to 5 km north of Middle Beach, adjacent to the Light River estuary, and in the north from Sandy Point, 10 km south of Port Wakefield, to the northern tip of Gulf St Vincent about 10 km north of Port Wakefield. Cyanobacteria mats also often occur within the intertidal salt marsh and mangrove communities. Seagrass are very abundant offshore of 2W2W (Figure 4.3, Loo and Drabsch 2008), with *Zostera spp*. being the most conspicuous in the intertidal and shallow subtidal, and *Posidonia australis* forming extensive meadows subtidally, in places with *Halophila* and *Zostera*, to a depth of about 15 m (Bryars et al. 2008). Macroalgal communities in the northern half of Gulf St Vincent are limited by the lack of hard substrata (only the 'Northern Reef' west of Port Parham is known) and as such macroalgae diversity is low with the species present typically growing in the soft sediments attached to shells and pebbles (Edyvane 2008).

The Dry Creek salt field, which was operated by Cheetham Salts Pty Ltd for Penrice Soda Pty Ltd until the latter's closure in 2015, stretch from Dry Creek just north of Port Adelaide to Webb Beach at Port Paraham, a distance of about 30 km along the coastline (Hough 2008). Production, which was focused on the manufacture of sodium carbonate and sodium bicarbonate, stopped with the closure of Penrice Soda in 2015. The salt ponds are now marked for housing development in the south, and elsewhere an international bird sanctuary, with some, adjacent to the northern pumping station and water inlet at Middle Beach, for other potential developments such as aquaculture.

When cut off from tidal inundation, organic carbon and carbonate oxidation of the sediments in salt marsh, mangrove and cyanobacteria mat areas can result in subsidence and the soils becoming acidic causing a significant ecological issue (Fitzpatrick et al. 2008). Mangroves can be affected by sea lettuce (*Ulva spp*.) blooms which proliferate as a result of high nutrients, with this seaweed blocking oxygen from pneumatophores and cause seedling mortality (Harbison 2008). Seagrasses have been most affected by elevated nutrients (e.g. Bolivar Sewage Treatment Works Outfall at St Kilda) and increased turbidity, with lesser impacts from the physical damage caused by the mooring systems of vessels, exceptionally low tides in hot weather and colonisation in a few places by the green algae, *Caulerpa taxifolia*. Nutrients stimulate macroalgal growth on the leaves of seagrasses that then reduce the light levels reaching the seagrass to support photosynthesis, increased sediments in the water can directly reduce light levels to the seagrasses or result in increased sediment on the leaves, which can also block light or weigh down leaves leading to increased abrasion on the seafloor. The anchors and chains of vessels mooring in seagrass beds can abrade/erode the plants, whereas seagrasses that become emergent at extreme low tides can desiccate. *Caulerpa taxifolia* can displace seagrasses by out competing them for space.

No aquaculture developments presently exist in the coastal zone of Gulf St Vincent adjacent to 2W2W, either on land or in the sea. Any future aquaculture ventures sited near the coast will need to consider the ecologically important native vegetation, particularly samphires, mangroves and seagrasses, as any construction of buildings, ponds, or pipelines will likely cause disturbance to these.

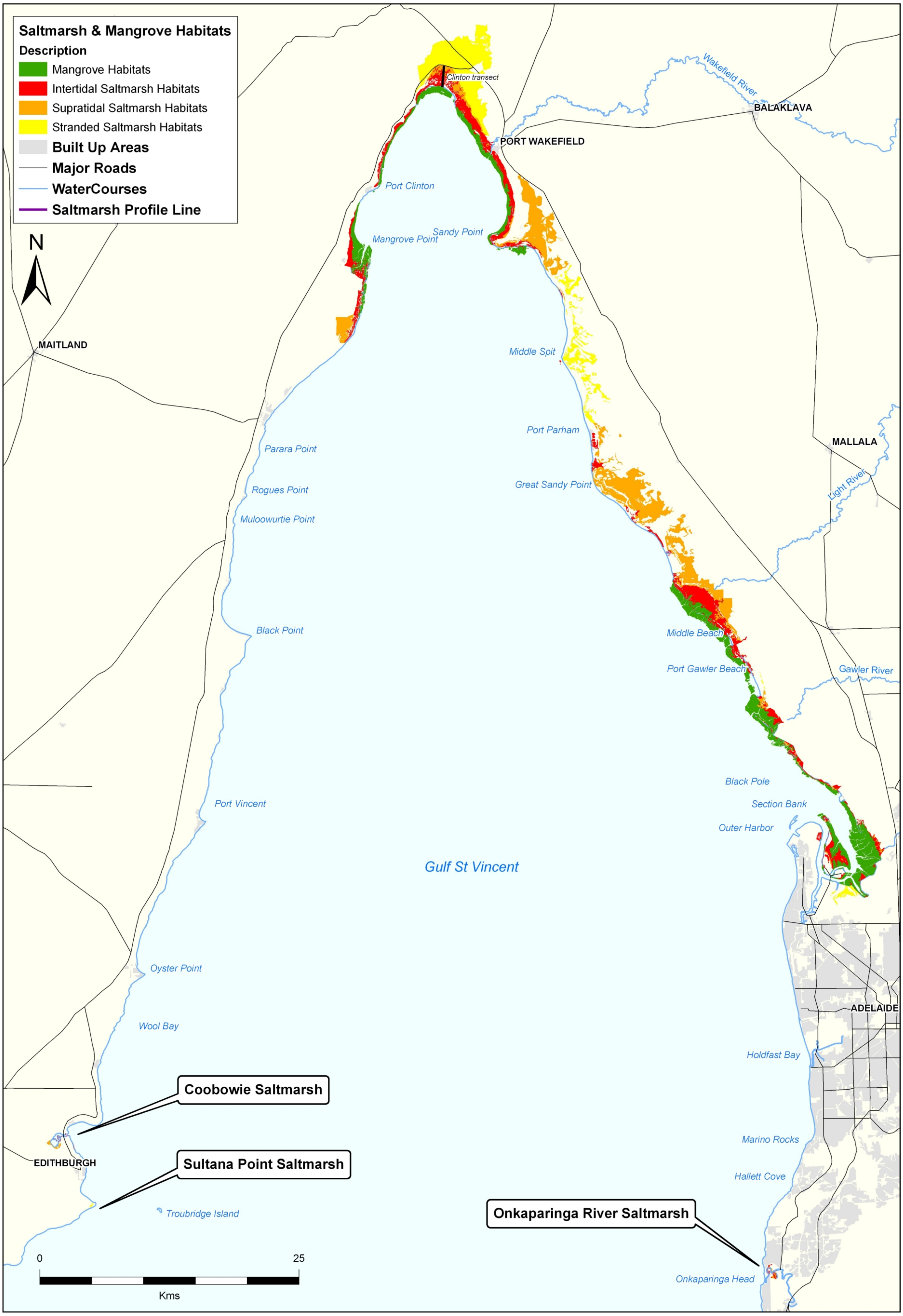

Figure 4.2. Salt marsh and mangrove habitats around Gulf St Vincent (source: Fotheringham and Coleman 2008).

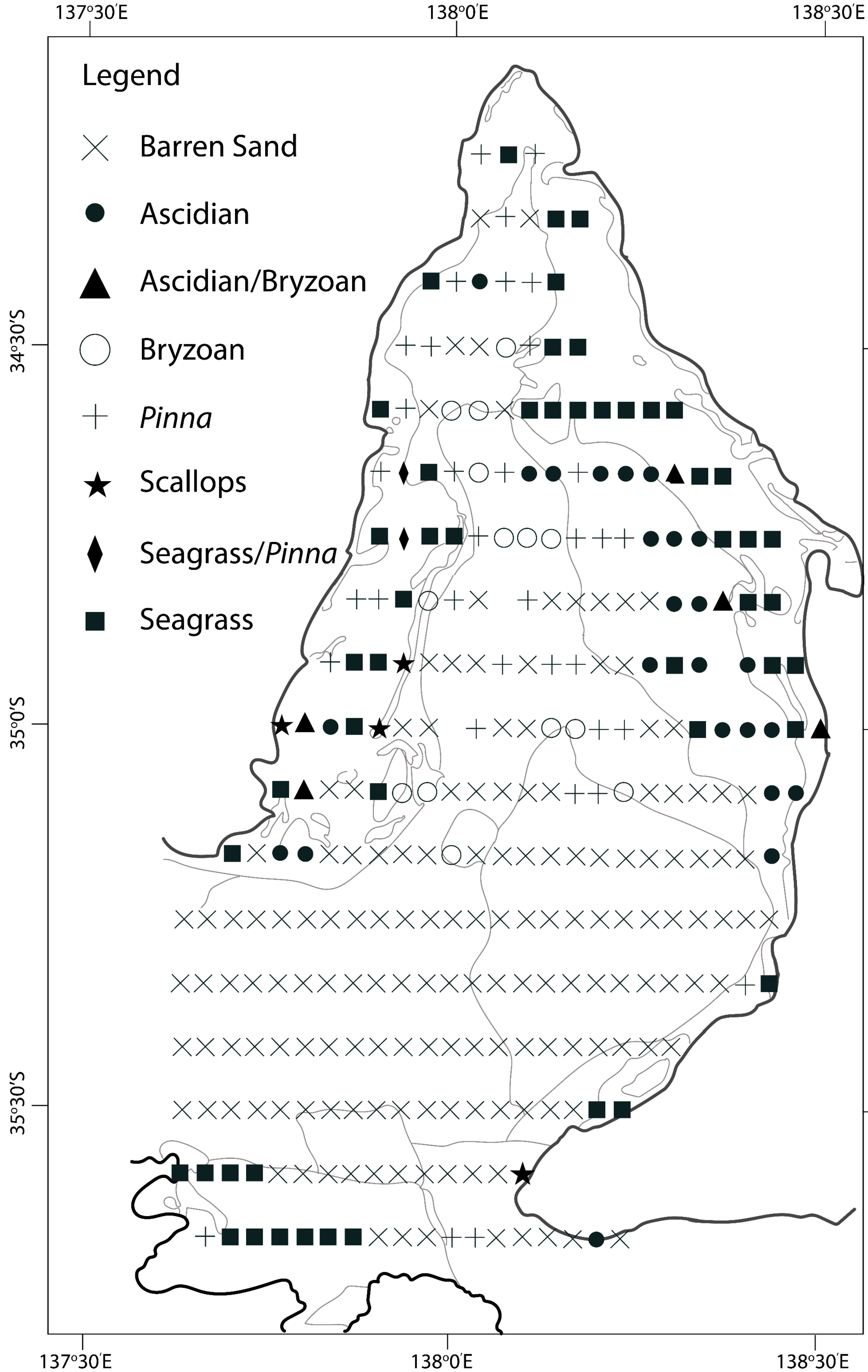

Figure 4.3. Major benthic communities of Gulf St Vincent (source: Loo and Drabsch 2008).

Spencer Gulf

Far northern Spencer Gulf is a shallow wave protected region, which is considered to be of high conservation value. It contains a variety of habitats and is considered to be the largest area of coastal and marine wetlands within South Australia, with some nationally significant and listed in the Directory of Important Wetlands (PPK 2002). North from a line from Cowleds Landing, 20 km south of Whyalla, east across Spencer Gulf to Jarrod Point, 23 km south of Port Pirie, is the 'Upper Spencer Gulf Marine Park', which is a general managed use zone, but which further includes three habitat protection zones, a number of special purpose areas, and nine sanctuary zones (Figure 4.4). The nine sanctuary zones are: Sanctuary Zone 1 (SZ-1) at the very head of the gulf north of Port Augusta; SZ-2 at Point Paterson - Redcliff Point; SZ-4 at Yatala Harbour; SZ-8 just south of Port Pirie; SZ-9 at Jarrold Point - Port Davis on the east of Spencer Gulf; SZ-4 at Blanche Harbour - Douglas Bank; SZ-5 at Black Point; SZ-7 at Whyalla - Cowlets Landing on the west side of Spencer Gulf; and SZ-6 in the middle of Spencer Gulf seaward of Whyalla. The Winninowie Conservation Park to the south extends from the coastline inshore adjacent SZ-2 and SZ-4.

In northern Spencer Gulf, mangroves, saltmarshes, intertidal mudflats and sandy beaches are common in the supertidal and intertidal areas, and seagrasses are common subtidally; which are all best developed on the shallower, gradually sloping eastern coastline of Spencer Gulf (Figure 4.5, Miller et al. 2014). The mangrove stands at Redcliff Point and Chinaman Creek are the largest undisturbed ones in South Australia (Dittmann and Baggalley 2014). Extensive seagrass meadows are common in waters less than 10 m deep with *Posidonia australis* and *P. sinuosa* dominant, and *Zostera*, *Halophila* and *Amphibolis* common; north of Redcliff Point *Zostera* is particularly abundant (Baker et al. 2014, Irving 2014). While no significant macroalgal dominated reef areas exist in this region, inshore algal communities near Craig Point are typical where a hard substrate is present and are composed of the brown algae *Scaberia agardii* in the upper stratum, *Cystophyllum onostum*, species of *Sargassum*, and *Botryocladia obovata* in the middle stratum, and *Lobophora variegata* in the lower stratum (PPK 2002).

Northern Spencer Gulf also has a unique faunal composition, with the coastal plant communities being ideal habitat for waterbirds and waders, including a variety of threatened species and ones listed under international treaties, and nursery and feeding areas for commercially important crustacean and finfish species. Seagrass meadows also support a wide diversity of invertebarates, including bryozoan, gastropoda, hydroids, echinoderms, polychaetes and ascidians.

Central Spencer Gulf (essentially from just south of a line from Whyalla on the west coast to Port Pirie on the east coast, south to a line from Cowell on the west coast and Moonta-Wallaroo on the east coast) has similar and extensive plant communities to northern Spencer Gulf on the eastern coast between Port Pirie and Port Broughton, part of 2W2W and the area of interest. From Port Broughton south to Wallaroo the coastline becomes more wave exposed and slopes more rapidly to greater water depths, and is characterised by interspersed rocky headlands and sandy beaches, often bounded behind by a sand dune or low cliff of up to about five metres high. Mangroves and samphire communities are not present in the supertidal except just south of Port Broughton, but the seagrasses *Posidonia angustifolia, P. sinuosa* and *Amphibolis antarctica* dominate the sandy seafloor subtidally to 15 metres depth along most of this coastline; brown algal communities dominate the shallow subtidal rocky areas where these occur.

About 15 km south of Wallaroo in the vicinity of Warburto Point is the Bird Island Conservation Park, which includes West and East Bird Islands. Tidal swamps with mangroves and samphire flats characterise this area (PIRSA 2017c).

Given the presence of a range of coastal conservation areas and sensitive biological communities in this region, any proposed coastal aquaculture development in 2W2W between Port Augusta and Port Broughton will need to be carefully considered in this region. However, further south from Port Broughton to Moonta-Wallaroo, particularly from Myponie Point to Point Riley, the more wave exposed coast has less of these sensitive ecological communities onshore. Farmland abuts the coastal strip, this providing greater opportunity for aquaculture development.

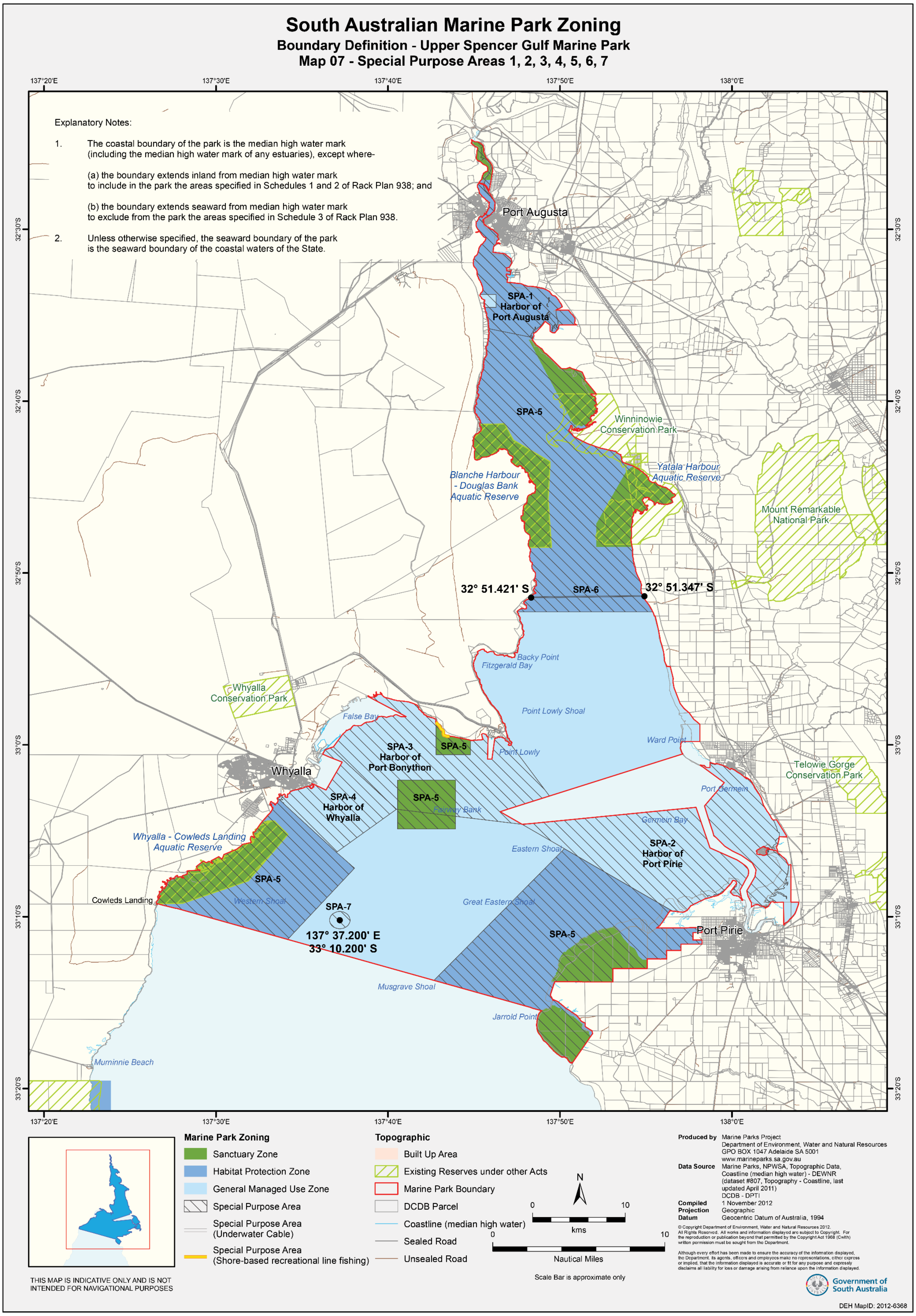

Figure 4.4. Upper Spencer Gulf region: marine and terrestrial parks, marine sanctuary zones and marine special purpose areas (source: National Parks and Wildlife Service South Australia 2017).

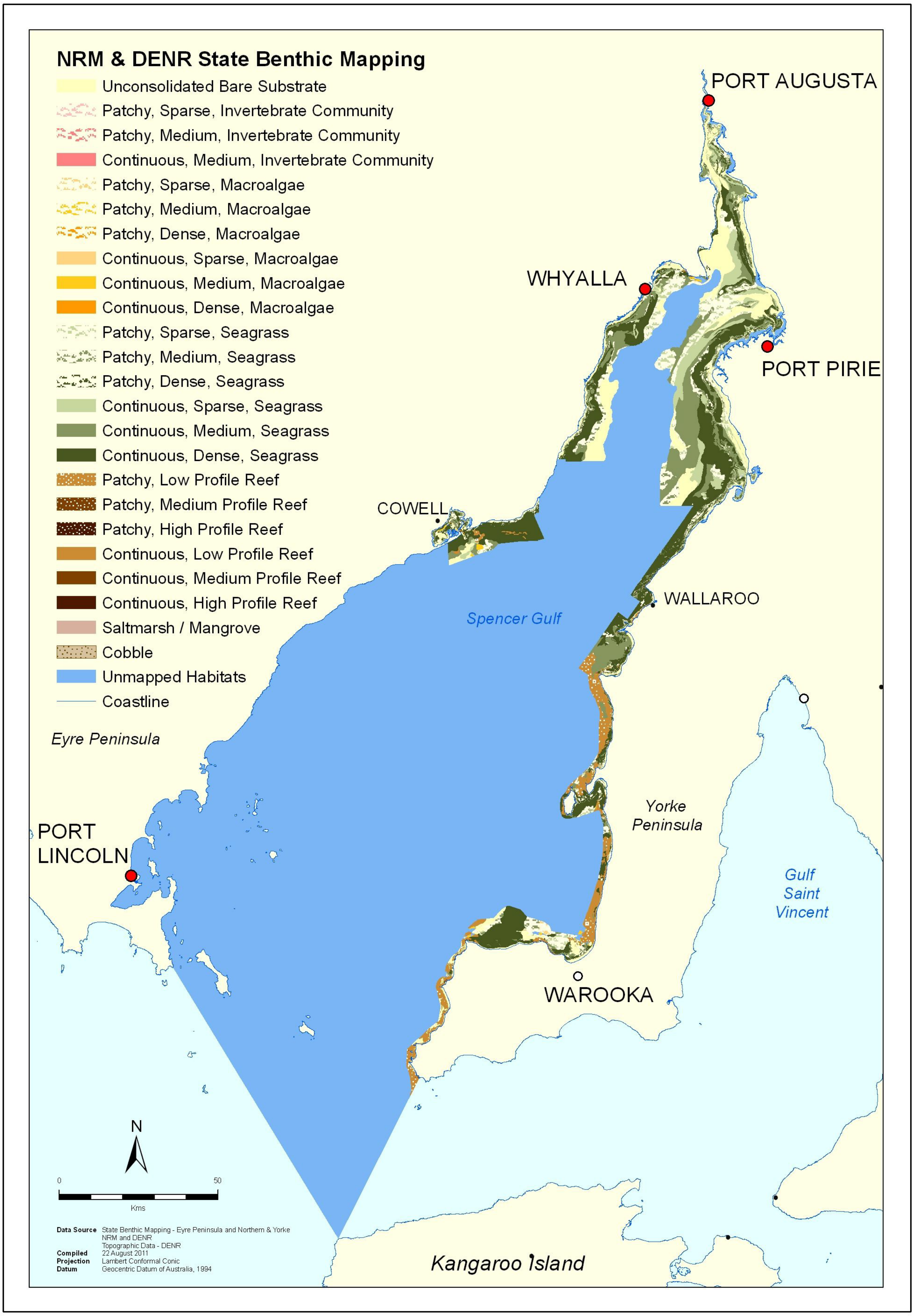

Figure 4.5. Major benthic communities of Spencer Gulf (source: Miller et al. 2014).

Native Title and heritage

Developments need to take into consideration known indigenous sites, Native Title claims and shipwreck sites, as well as such undocumented sites. All are relevant to specific areas of 2W2W, with the highest density of indigenous sites to the north and south of Wallaroo and around Port Bonython to Point Lowly, northeast of Whyalla (PPK 2002). Shipwrecks, of which many are still to be located, are believed to be in the vicinity of Moonta, Port Broughton, Port Pirie, Blanche Bay south of Port Augusta and Whyalla (PPK 2002).

The Aboriginal Heritage Unit, South Australian Department of Premier and Cabinet and Aboriginal Partnerships Unit, Rural Solutions SA, PIRSA can provide the most effective procedures to access aboriginal heritage site and object registers, communicate with relevant aboriginal communities, and undertake any heritage surveys required. The South Australian Department for Environment and Water (DEW) maintains a register of shipwrecks and administers the relevant legislation and regulations.

4.3. Water

An adequate supply of suitable quality water is a fundamental component of any aquaculture operation, with the normal sources being surface waters (e.g. rivers, streams, dams, ponds), or groundwaters (e.g. bores, wells). n general, groundwater, if of appropriate quality, provides a more constant supply and quality, but this may not always be the case as groundwater contamination can occur, particularly from certain industrial and commercial uses and historically poor capture of wastes from such operations (e.g. mining tailing storage and ore processing or herbicide and/or pesticide residues from some forms of agriculture use).

Both water quality and quantity have a direct bearing on what aquatic species can be grown at a particular site, as well as identifying infrastructure requirements and management procedures that may need to be put in place to address sub-standard levels of some parameters. As water testing can be expensive and not every possibly relevant parameter can typically be tested, aquaculturists should also comprehensively research the history of the site and the water resource they will use, including its catchment area. It is also recommended that small scale trials are undertaken to culture the species of interest in the water to be used and to subsequently test the products produced for any potential chemical residues that might be of concern during marketing. The Department of Primary Industries and Fisheries, Queensland Government has produced a useful guide for aquaculturists seeking to assess chemical contamination during the site selection process (DPIF QLD 2005). The South Australian

Environmental Protection Authority (EPA) keeps a register of known contaminated sites and will provide relevant information for any site for which information is sought.

Parameters typically evaluated for land-based aquaculture include:

- annual temperature range;
- pH;
- conductivity, salinity and/or total dissolved solids;
- cations (sodium, potassium, calcium and magnesium);
- anions (chloride, bicarbonate, carbonate and sulfate);
- heavy metals (copper, iron, zinc);
- cadmium;
- toxic metabolites (e.g. hydrogen sulphide, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen);
- turbidity;
- gases (dissolved oxygen, carbon dioxide, and nitrogen); and
- pesticides (e.g. DDT and Dieldrin).

Water quality guidelines and standards should be used with caution as many antagonistic effects occur between parameters, and their effect on aquatic organisms is also influenced by the susceptibility of the life stage of a particular species, which have tolerances that vary considerably, and the health/stress level of the species. It is also important to recognise that lethal and sublethal effects need to be considered. For example, a detrimental effect on the growth of the cultured species can result in a venture becoming unprofitable. The rate of change of many parameters is also critical as too fast a change will cause sublethal and then lethal effects.

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) provide a comprehensive listing of the physico-chemical stressor and toxicant guidelines for the protection of aquaculture species cultured for freshwater and marine waters in Australia. Table 4.1 provides a subset of this information, focused on the physio-chemical and inorganic toxicant parameters considered of most relevance and likely to be assessed in South Australia. Philnimaq (2008) includes comparable data for a number of Asian countries, Norway/Canada and the USA for comparison. Boyd (1979), in describing water quality in ponds for aquaculture, provides useful information on the lethal and sublethal effects of many water quality parameters on common freshwater aquaculture species, as well as describing the complex workings and interactions of many of the parameters in aquaculture.

Table 4.1: Physico-chemical stressors and inorganic toxicants relevant to freshwater and marine aquaculture in South Australia (source: ANZECC 2000).

Parameter	Unit	Freshwater	Marine
Alkalinity	mg L^{-1}	>20	>20
Carbon dioxide	mg L^{-1}	<10	<15
Dissolved oxygen	mg L^{-1}	>5	>5
Gas supersaturation	mg L^{-1}	<100%	<100%
Hardness	mg L^{-1}	20-100	NC
pH	mg L^{-1}	5.0-9.0	6.0-9.0
Salinity	ppt	<3.0	33.0-37.0
Suspended solids	mg L^{-1}	<40	<10
Temperature	°C	<2.0°C over 1 hour	<2.0°C over 1 hour
Aluminium	ug L^{-1}	<30 (pH >6.5) <10 (pH <6.5)	<10
Cadmium (varies with hardness)	ug L^{-1}	<0.2-1.8	<0.5-5
Chlorine	ug L^{-1}	<3	<3
Chromium	ug L^{-1}	<20	<20
Copper (varies with hardness)	ug L^{-1}	<5	<5
Fluorides	ug L^{-1}	<20	ND
Hydrogen sulfide	ug L^{-1}	<1	<2
Iron	ug L^{-1}	<10	<10
Lead (varies with hardness)	ug L^{-1}	<1-7	<1-7
Magnesium	ug L^{-1}	<15,000	ND
Manganese	ug L^{-1}	<10	<10
Mercury	ug L^{-1}	<1	<1
Nickel	ug L^{-1}	<100	<100
Selinium	ug L^{-1}	<10	<10
Silver	ug L^{-1}	<3	<3
Vanadium	ug L^{-1}	<100	<100
Zinc	ug L^{-1}	<5	<5
NH4 (ammonium)	mg L^{-1}	<1.0	<1.0
NH3 (ammonia – un-ionised)	mg L^{-1}	<0.02 (pH >8.0) coldwater <0.03 (warmwater)	<0.1
NO3 (nitrate)	mg L^{-1}	50	<100
NO2 (nitrite)	mg L^{-1}	0.10	<0.10
TAN (total available nitrogen)	mg L^{-1}	1.0	<1.0
PO4 (phosphate)	mg L^{-1}	<40	<0.05

While the information in Table 4.1 implies that the tolerances and optima of water quality parameters are simple, this is far from the case due to these levels varying between the different life stages of species and because of antagonistic and/or synergistic effects that can occur between parameters. To illustrate this, potassium, a parameter not included in Table 4.1, has been found from past inland saline groundwater aquaculture R&D to be critical to the survival and growth of many aquaculture species. Fielder et al. (2001) addressed Snapper mortalities by raising potassium levels in their holding water from 9.2 to 83 mg L^{-1}, and found that growth continued to improve to a level of 124 mg L^{-1} after which there was no further improvement to 207 mg L^{-1}, the level in seawater diluted to 19 ppt, the salinity level of the groundwater at the site. Hutchinson and Flowers (2008) found that Yellowtail Kingfish growth was greatly reduced at a potassium level 37.6 mg L^{-1}, but much improved at 204 mg L^{-1} and Hutchinson and Skordas (2014) determined that Western King Prawn grew better in groundwater fortified with potassium, to raise it from 97 to 217 mg L^{-1}. Doroudi et al. (2006) reported improved survival of Mulloway at potassium levels >78.7 mg L^{-1}, with good growth at >82.8 mg L^{-1}.

Partridge and Creeper (2004) developed on the work of Fielder et al. (2001) and suggested that potassium needed to also be considered in relation to the amount of chloride present in the water. Fielder et al. (2001) reported total mortality of Snapper at a potassium:chloride ratio of 0.001, with survival increasing at 0.008 and further improving at 0.013.

When considering the levels of chemical residues in water (e.g. herbicides and pesticides), it is important to recognise that the level of detection for each parameter tested by the analytical laboratory must be below the water quality criteria guideline for that parameter, to be useful. If the level of detection is above the water quality criteria, as is often the case for data reported in South Australia, then one cannot be certain that the water sampled meets with the guidelines.

The WaterConnect web site https://www.waterconnect.sa.gov.au/Pages/Home.aspx, provides the latest information about most of South Australia's land-based water resources, including providing direct access to water-related data and publications. It includes links to available data for all bores, drill and holes (inclusively referred to as bores within this report), to water management reports (for PWRA and Non-Prescribed Water Resource Areas – N-PWRA) and provides details of the water access application processes.

DEW is the South Australian Government agency that issues water licences and allocations , with the EPA Water Quality Policy 2015 (EPA South Australia 2017) supporting legislation for providing the structure for regulation and management of water quality in South Australian inland surface waters.

DEW manages PWRAs to ensure water use is sustainable under the Natural Resources Management Act 2004 by the issuing of water licences that endorse a water entitlement. Activities that require a licence vary depending on the water resources prescribed within a region, but typically include underground, watercourse or surface water extracted for such uses as irrigation, commercial, domestic, industrial, irrigation of crops, watering of stock and managed aquifer recharge. To enable monitoring and regulation, DEW may also issue a permit for activities that could impact on a water resource or an ecosystem that depends on one, for example: drilling, plugging, backfilling or sealing of a well; repairing, replacing or altering the casing, lining or screening of a well; draining or discharging water directly or indirectly into a well; using imported water in the course of carrying on a business; using effluent in the course of carrying on a business; erect, construct or enlarge a dam; draining or discharging into a watercourse or lake; and conduct a water affecting activity in a watercourse, floodplain or lake.

4.3.1. Surface waters

River basins

The main river basins, as defined by the Australian Water Resources Council in the early 1960s, which lie in part within 2W2W, are from north to south (DEWNR 2013):

- Mambray Coast Basin, which is 5,900 km^2 in area, with its small watercourses flowing from the western side of the Flinders Ranges to discharge into the northern areas of Spencer Gulf.
- Broughton River Basin, which is 16,300 km^2 in area, and bounded in the west by the Southern Flinders Ranges where the average annual (1900-2010) rainfall was 600-700 mm compared to 300-400 mm near the coast. The major watercourse of this catchment is the Broughton River, which is about 145 km in length and flows from about 750 m above sea level in the northwest, to about 110 m above sea level at Crystal Brook to the east of the coastal plain, to where it enters Spencer Gulf between Port Broughton and Port Pirie (about 20 km south of Port Pirie). The Broughton River is an ephemeral system, characterised by irregular stream flows; groundwater is considered important in maintaining base flow (DEWNR 2013).
- Wakefield River Basin, which is 1,900 km^2 in area and includes the Wakefield River Catchment. This is bounded in the west by the Northern Mount Lofty Ranges where the average annual (1900-2010) rainfall was about 700 mm as compared to on the coast where it was about 350 mm. The major watercourse of this catchment is the Wakefield River, which is about 115 km in length, flowing from a height of about 600 m above sea level in the northern parts of the

catchment to about 65 m above sea level at Balaklava to the east of the coastal plain, to where it enters Gulf St Vincent at Port Wakefield through a mangrove-estuarine system.

- The Gawler River Basin, which is 4,550 km^2 in area and includes the Light River and Gawler River catchments. The Light River Catchment flows in a south-westerly direction, bounded in the north and west by the northern Mount Lofty Ranges where the average annual (1900-2010) rainfall was about 600 mm as compared to about 400 mm near the coast. The major watercourse of this catchment is the Light River, which is about 170 km in length and within 2W2W unlike the Gawler River, which is to its south. The Light River flows from a height of about 600 m above sea level in the north and west of the catchment, to the southwest where it enters Gulf St Vincent about 5 km north of Middle Beach. It is an ephemeral system, characterised by irregular stream flows and long dry intermediate periods; groundwater driven base flow maintains stream flow and permanent pools occur in the upper portions (DEWNR 2013). Rainfall of greater than 450 mm is needed to saturate the catchment and generate significant stream flows in the Light River; permanent groundwater tends only to drive base flow in upper tributaries (DEWNR 2013).

Surface water storage

Surface water storage in the N&YNRMR comprises farm dams and public reservoirs (Figure 4.6, DEWNR 2013). Farm dams in the Wakefield, Broughton, Light and Willochra catchments, which in part includes 2W2W, number about 8,800 with an estimated volume of about 22,000 ML, although many of these are associated with higher relief areas outside 2W2W. Three regional reservoirs also occur within the central N&YNRMR; from south to north, the Bundaleer (60 km south-east of Port Pirie) has a capacity of 6,370 ML and surface area of 63 ha; and within 2W2W, the Beetaloo (20 km east of Port Pirie) has a capacity of 3,180 ML and surface area of 33 ha and the Baroota (35 km north of Port Pirie) has a capacity of 6,140 ML and surface area of 63 ha (DEWNR 2013). These were built between 1890 and 1921 and have been largely unused since potable reticulated water systems were modernised in the past few decades (Goyder Institute 2016b).

Some water quality parameters of each of the three reservoirs have been reported and evaluated (Goyder Institute 2016b) against the Australian and New Zealand criteria for freshwater and marine water quality (ANZECC 2000) for irrigation, livestock drinking water and aquaculture. Overall, the water quality of the reservoirs was considered undesirable as a source for aquaculture as they typically have low dissolved oxygen (as low as <0.5 mg L^{-1}), high pH (up to 9.3), and above recommended levels of aluminium, iron, manganese, zinc and in some instances copper and coliform bacteria. Also, the levels of detection of a number of agricultural pesticides was above the recommended levels, so it is uncertain whether these may be of concern or not.

The South Australian Government has investigated and approved the use of these three reservoirs for intensive agriculture activities, as well as for shore-based recreational fishing (e.g. Goyder Institute 2016b). Any such use must, however, align with the variable level of water which can occur in these reservoirs as evidenced by the Baroota Reservoir reaching the spill height of 23 m only six times between 1978-2010 and the Beetaloo Resevoir being below the minimum recording level of 6.5 m in 1981 and completely drying in 1982 for the period 1980-2008. Presently the Bundaleer, Warren (near Williamstown in the Mount Lofty ranges) and Todd (near Port Lincoln, Eyre Peninsula), which are outside the boundaries of 2W2W, have been approved for recreational fishing, as has the Beetaloo Reservoir within 2W2W. In association with relevant Councils and RecFish SA, the peak recreational fishing body in South Australia, funds have been committed to improving shore facilities, with RecFish SA having stocked native finfish species such as Golden Perch, Silver Perch and Murray Cod, as well as the non-endemic species, Rainbow Trout and Brown Trout. Previously non-endemic European Carp (*Cyprinus carpio*), Mosquito Fish (*Gambusia sp.*) and Redfin Perch (*Perca fluviatilis*) are the only species to have been recorded from these reservoirs, except for the Bundaleer where Brown Trout and Rainbow Trout have previously been stocked.

The Goyder Institute (2016b) report that projections for reductions in median annual runoff in the Baroota Reservoir catchment due to climate change, the only area where this has been determined within 2W2W, are between 9-12% in 2030 and 16-27% in 2070.

4.3.2. Groundwater

Two Wells to Whyalla Regional Corridor (2W2W)

Most of the N&YNRMR and thus the 2W2W is a non-prescribed water resources area (N-PWRA). As such, groundwater can potentially be freely accessed through application to DEW. The only PWRA within 2W2W is the Baroota PWRA, an area of 130 km^2 about 25 km north of Port Pirie, on the coastal plain between the Flinders Ranges and Spencer Gulf (DEWNR 2014). Here it is likely that aquaculturists will only be able to access water by using existing entitlements (either by purchasing water licences or by putting aquaculture in-line so as to use only the existing water entitled).

Across the N&YNRMR there are records for 21,181 bores, 8,746 with salinity information but only 697 of these recorded in the last decade (Alcoe and Berens 2011); 8,702 with depth to groundwater but only 1,186 in the last decade; and 4,994 with yield but only 636 in the last decade. Using WaterConnect on-line, information was sought on water temperature a key parameter in determining the growth rate, food conversion efficiency, health and survival of aquaculture species, but while a column exists in the database for such information, no such data was located. Minimal information also exists on important water quality parameters of relevance to aquaculture (e.g. nutrients, trace metals, toxins and agricultural chemical residues).

In general, groundwater salinity is measured as Total Dissolved Solids and provided in milligram litre^{-1}, but in this report it is reported as salinity in parts per thousand (ppt); seawater is typically 35-36 ppt. Figure 4.7 highlights that groundwater salinity varies considerably within 2W2W. Lower salinity groundwater, less than 1.5 ppt, is most abundant inland on the coastal plain about 35 km east-north-east of Port Wakefield, in the Baroota PWRA and along the western margin of the Southern Flinders Ranges between Crystal Brook and Port Augusta. Alternatively, high salinity groundwater, between 5.0-20 ppt and greater than 20.0 ppt, is most abundant adjacent to the coast, and across most of the coastal plain between the Copper Coast (Moonta and Wallaroo) and Port Pirie, and from south of Port Augusta to Whyalla.

In general, standing water level, which is the distance from the surface of the bore/well hole to the top of the water in metres when no pumping is taking place, has a spatial distribution that closely matches that for salinity within 2W2W, with the considerable variability typically correlated with variations in topographic relief (Figure 4.8, Alcoe and Berens 2011). Low standing water levels (0-10 m) are typically adjacent the coast and high standing levels (50-173 m) typically in the raised topography along the western margin of the Southern Flinders Ranges, with intermediate values between.

Groundwater bore or well yield, which is the flow rate when pumping, is typically measured at the time of drilling in litre second^{-1} and is influenced by such factors as the availability and depth of groundwater, the nature of the bore and the capacity of the pump used. Within 2W2W bore yields are predominately <1 L s^{-1}, with most of the others <3 L s^{-1}. Very few bores exist that have yields between 5-10 L s^{-1} or >10 L s^{-1}; a few exist about 15-35 km east of Port Wakefield, a couple east of Snowtown, a few south-west of Crystal Brook, and a few in the Baroota PWRA (Figure 4.9, Alcoe and Berens 2011).

Of particular interest near Balaklava is one bore with a production depth of 95-158 m and a salinity of 30 ppt (close to seawater and suitable for most marine species), as well as two bores close by but to the east of this with a production depth of 81-85 m and salinities of 2.4-3.2 ppt (only slightly saline and suitable to most freshwater native species). Also, the bore at the Balaklava Golf Club has a production depth of 61 m and a flow of about 15 L s^{-1}, a salinity of 2.0-2.1 ppt and a pH of 7.0-7.5 (SADF 1991).

Northern Adelaide Plains

Just south of the southern extent of 2W2W is the NAP PWRA, located directly north of the Adelaide metropolitan area and in the Mount Lofty Ranges Natural Resource Management Region (MLRNRMR). This is considered here in detail because of the greater understanding that exists of its groundwaters, particularly their salinity and because some of its aquifers extend north into the 2W2W (Figures 4.10, 4.11 and 4.12).

The shallowest aquifer in the NAP is a perched aquifer, which is formed when infiltrating surface water is hindered by a low permeability layer, potentially leading to water logging or flooding in times of high rainfall. Below this there are up to four quaternary aquifers, Q1-4, from shallower (Q1-3 from about 1-30m deep) to deeper (Q4 at about 50-90 m deep), over most of the PWRA (Figure 4.12). Within these shallow aquifers, salinity is highly variable and yields low. Water temperatures varies seasonally between about 16-20°C (pers. comm. Bryan Robertson, Hortex, 2017).

The T1 aquifer (DEWNR 2017a) is the main source of groundwater in the southern half of the PWRA where it occurs at a depth of about 130-160 m, sloping up to a depth of about 30 m in the north (Figure 4.12) adjacent the Gawler River. It is absent in the north-east portion of the NAP. T1 aquifers are used for horticulture, commercial and industrial activities. T1 bores predominately have salinities (Figure 4.10) of 0.5-1.0 ppt and most less than 1.5 ppt, although 3.0 ppt has been recorded from some. In the coastal area to the south-west of Two Wells salinities are predominately between 1.0-1.5 ppt. From 2011-2016 salinities and pressure have been relatively stable with the extraction rate at 3,429 ML, which is about 2% more than the year before.

The water level of T1 bores can vary 5-10 m in response to seasonal pumping intensity (much higher in summer). Water temperatures are typically in the range of 15-18°C varying seasonally and being higher in summer than winter (pers. comm. Mr Bryan Robertson, Hortex, 2017).

T1 aquifer bore salinities on the coastal plain o between Two Wells and Port Wakefield (Figure 4.10, DEWNR 2017a) are generally characterised by salinities near the coast of 7-14 ppt and further inland of 3-7 ppt, except at a few locations where they are 2-3 ppt, before rising again along the western margin of the Mount Lofty Ranges.

Specific examples of the characteristics of the ground water in this region south of the Australian Defence Force Proof Firing Range are (Water Connect SA 2017):

- Wild Horse Plains: 8.6-9.5 ppt (Total Dissolved Solids, TDS), with standard water level at 30-36 m and yield 1-10 L s^{-1} (but one 36 ppt).
- Port Parham: 1.8-8.2 ppt (TDS), with standard water level at 3-119 m and yield 0.3-9 L s^{-1} (but one 24 ppt).
- Middle Beach: 4.2-9.2 ppt (TDS), 9-183 m and yield 0.25-20 L s^{-1} (but one at 34 ppt).

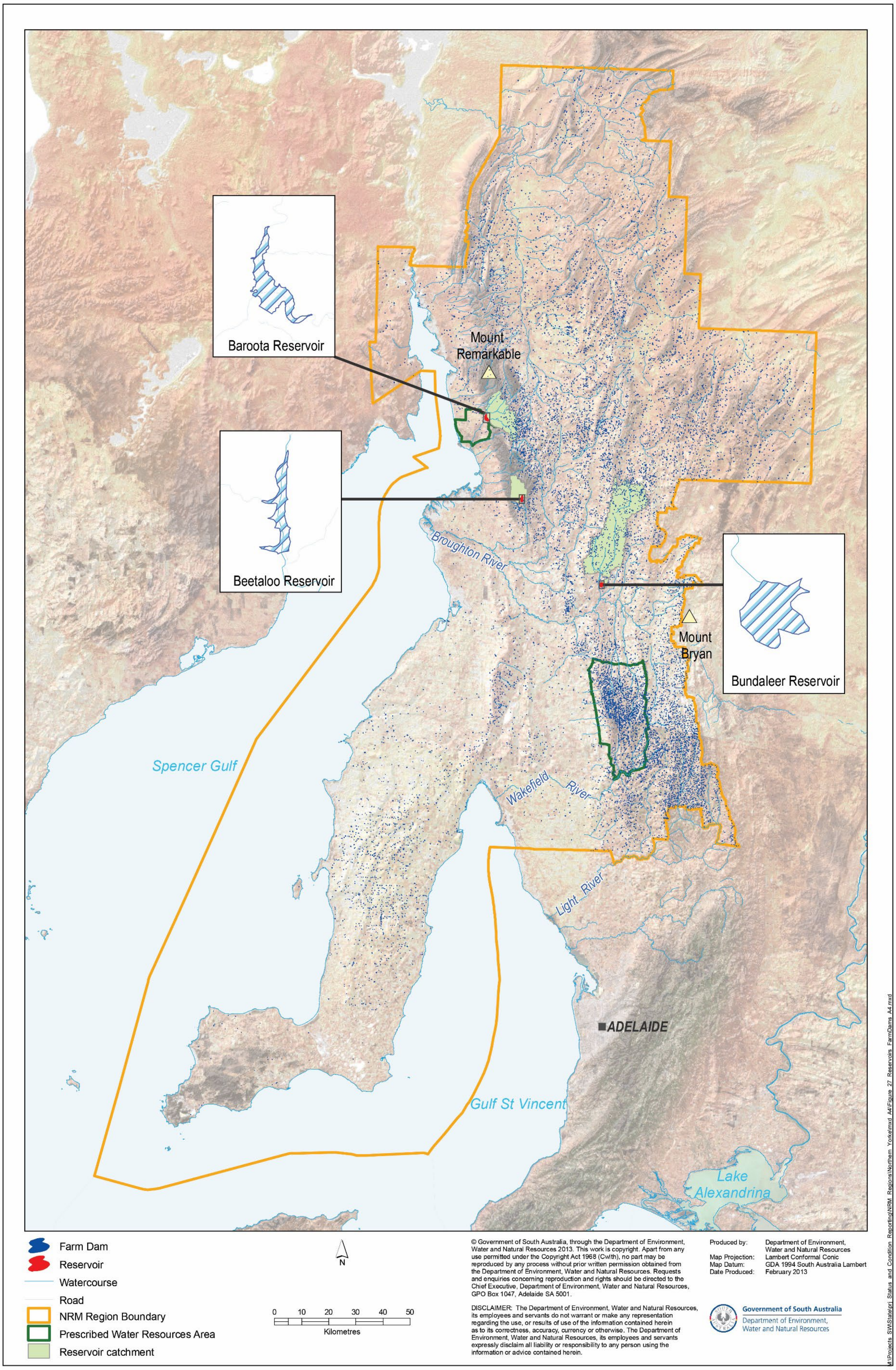

Figure 27. Reservoirs and farm dams in the Northern and Yorke NRM Region

Figure 4.6. Farm dams and reservoirs within the Northern and Yorke Natural Resource Management Region (source: DEWNR 2013).

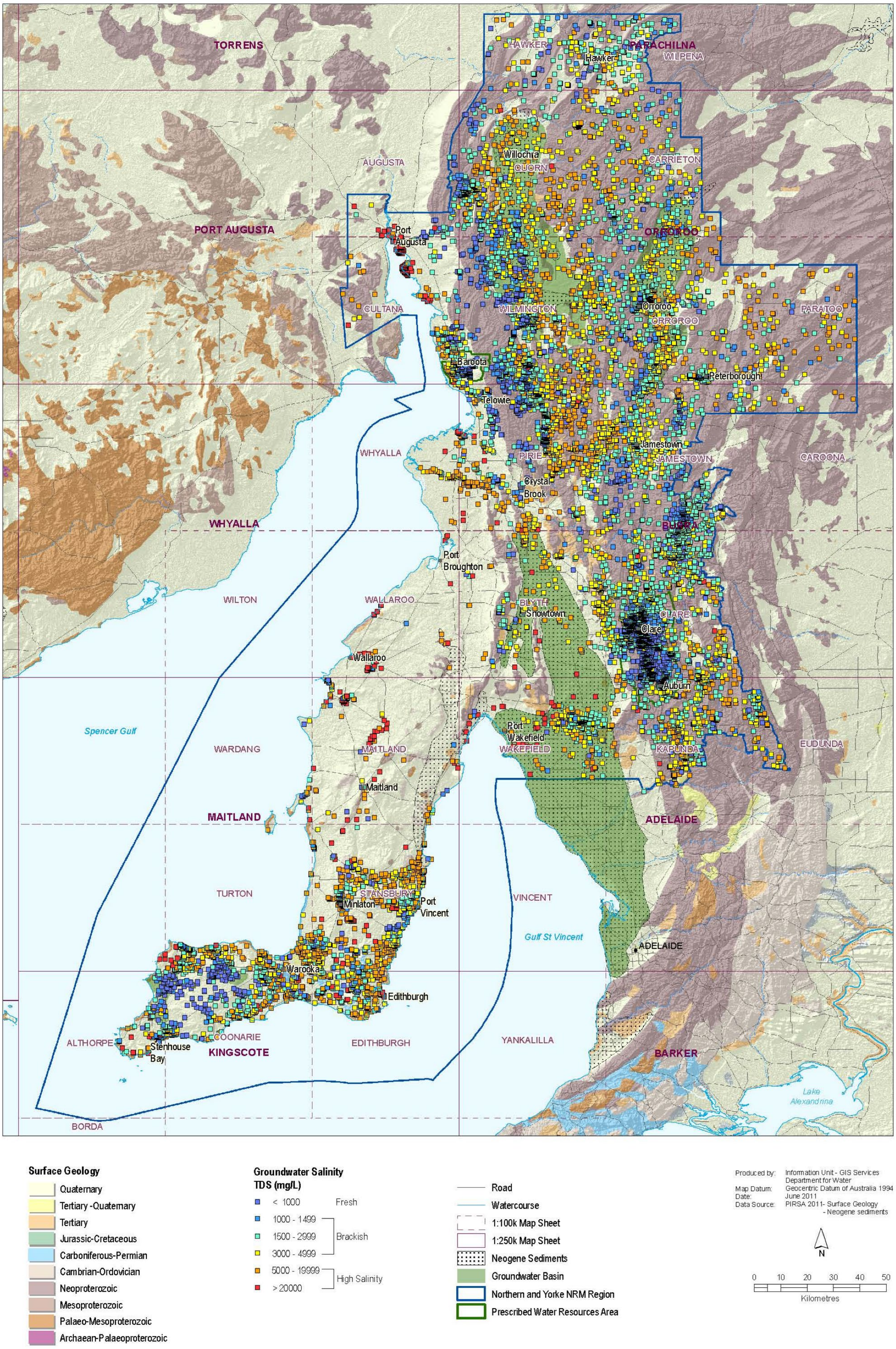

Figure 4.7. Groundwater salinity for bores within the Northern and Yorke Natural Resource Management Region (source: Alcoe and Berens 2011).

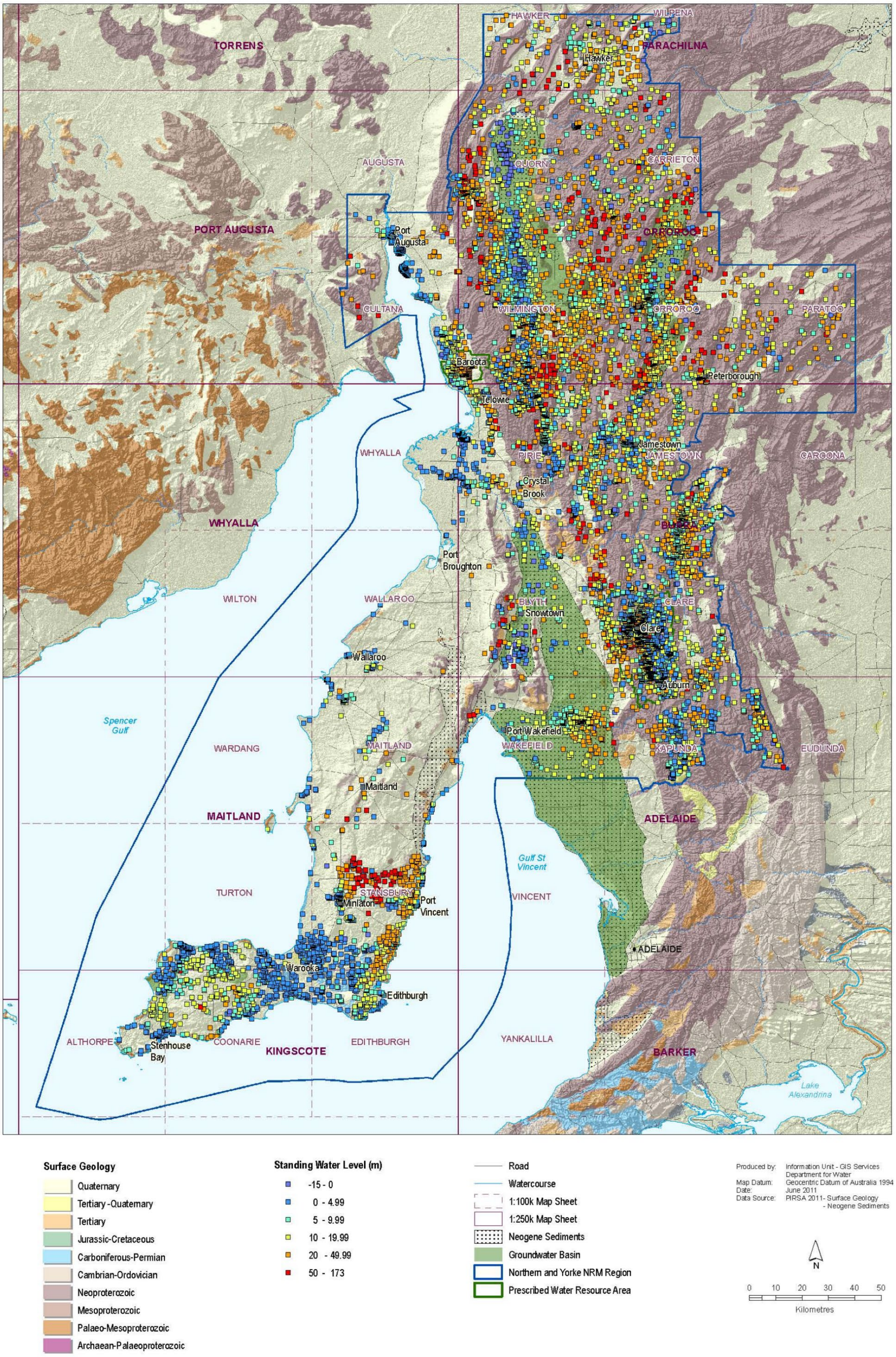

Figure 4.8. Groundwater standing water level for bores within the Northern and Yorke Natural Resource Management Region (source: Alcoe and Berens 2011).

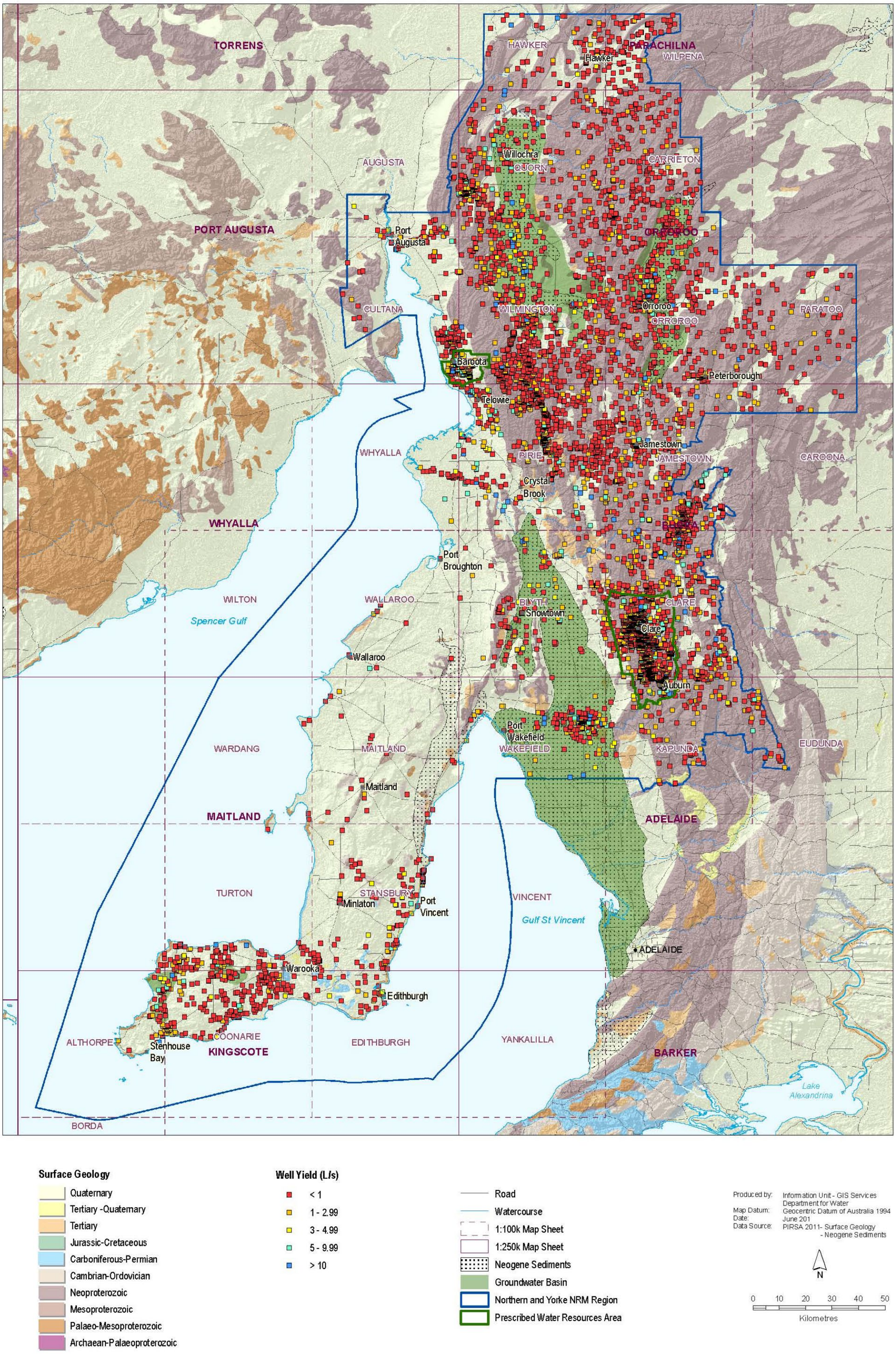

Figure 4.9. Groundwater well yield for bores within the Northern and Yorke Natural Resource Management Region (source: Alcoe and Berens 2011).

Whereas inland they are:

- Owen: 2.6-15.5 ppt (TDS), with standard water level at 26-150 m and yield 0.5-5 L s^{-1}.
- Long Plains: 2.9-9.6 ppt (TDS), with standard water level at 42-121 m and yield 6-18 L s^{-1}.
- Mallala: 2.8-6.7 ppt (TDS), with standard water level at 20-85 m and yield 0.13-18.9 L s^{-1}.

Water temperature of T1 bores on the northern part of Torrens Island, near Middle Beach, and near Two Wells were identified as about 20°C, and varying by only about 0.5°C seasonally (data provided by Travis Kleinig, EPA 2017). Salinity and production depth for these three bores were, respectively, 0.6 ppt and 95-110 m, 2.2 ppt and 116-122 m, and 0.8 ppt and 75 m. A comparison of the water quality data for these bores with general aquaculture water quality requirements (e.g. Boyd 1990), demonstrates that their water is suitable for aquaculture with minor treatment, recognising that the water is hard (higher calcium and magnesium levels), has almost no dissolved oxygen present and has a slight hydrogen sulfide smell when sampled.

Beneath the T1 aquifer is the T2 aquifer, which occurs throughout the NAP but not north into 2W2W (DEWNR 2017b, Goyder Institute 2016a). The T2 aquifer underlies the Munno Para Clay confining layer between a depth of about 170-260 m in the south, shallowing to a depth of 10-45 m in the north (Figure 4.12). It is the predominant aquifer utilised in the northern part of the PWRA between Virginia and Gawler with total extraction 9,517 ML in 2015-16, about 12% higher than the previous year. Despite this increased extraction rate, groundwater pressure and salinities are stable or improving. In 2016 salinities ranged from 0.2 – 9.2 ppt but with 79% of the bores (266) less than 1.5 ppt, with the predominant low salinity bores (0.5-1.0 ppt) mainly around Virginia and along the Gawler River (Figure 4.11). At Two Wells bore salinities are typically in the range of 3.0-5.0 ppt whereas slightly further south and west they are 1.5-3.0 ppt, although one is greater than 8.0 ppt.

The T2 aquifer is of particular interest as temperature and salinity data from three bores that draw on the T2 acquifer indicate suitability for finfish aquaculture. Bores located at West Beach (depth about 200 m), Torrens Island and St Kilda (depth about 100 m) have groundwater temperatures of about 24-26°C and salinities between 1.1 – 1.5ppt (pers. comm. Dwayne Stephenson, SARDI; Mr Andrew Poligerinos, Robarra; and Mr Jack Lee, Mark Lee Barramundi Farm, 2016). Water temperatures of 25.5±0.4°C and 26.0±1°C were recorded, respectively, for T2 bores at 160-220 m depth at Parafield and at 100-160 m depth at Bolivar (Vandeperzalm et al. 2010). Page et al. (2013) indicates a T2 aquifer median water temperature of 24.9°C. A comparison of the water quality data for the bore at SARDI and bores presented in Vanderzalm et al. (2010) and Page et al. (2013) with general aquaculture water quality requirements (e.g. Boyd 1990), demonstrates that T2 groundwater is suitable for aquaculture with minor treatment, although recognising that the water is hard (high calcium and magnesium levels and a median hardness (calcium carbonate) of 766 mg L^{-1}), and that ammonia as nitrogen (median 0.036 mg L^{-1}), true colour (42), fluoride (median 0.43 mg L^{-1}), total iron (median 1.52 mg L^{-1}) and total zinc (0.035 mg L^{-1}) are elevated above the values within the Australian and New Zealand Guidelines for Fresh and Marine Water Quality at some locations, and that as expected dissolved oxygen levels are very low (Adell 2017 provides the actual levels).

No direct recharge of T1 and T2 aquifers is believed to occur from rainfall in the region. The main source of recharge is thought to be lateral through flows from the Mount Lofty ranges to the east, where rainfall recharge occurs to the fractured rock aquifers present, with water then flowing west towards the coast.

The distribution of the T3 and T4 aquifers is not well known, but they are thought to underlay most of the NAP at depths of 210-260 m to the south (and occasionally north) of Maslin Sands, which directly over-lie the basement fractured rock aquifer (Goyder Institute 2016a). Their groundwater is said to be more saline than seawater, which has not been of interest to-date to agriculture, commercial and industrial users, although it may be suitable for aquaculture.

Climate change

Groundwater availability in the shallow and unconfined quaternary aquifers of the NAP (Q1-4) and to the north of the NAP (to Port Wakefield) have been predicted to potentially decline by as much as 44% as a result of decreased local rainfall, decreased groundwater recharge in the Western Mount Lofty Ranges and higher evapotranspiration, suggesting they have a moderate to high sensitivity to climate change (Goyder Institute 2016a). Alternatively, the groundwater availability from the deeper, confined tertiary aquifers of the NAP (T1 and T2) and to the north (T1) have been suggested to have a low sensitivity to climate change, primarily because they are thought to be recharged by water flowing laterally and down-stream from connected aquifers rather than by downward infiltration of rainfall, although adjacent aquifers may also be affected by climate change and cause effects that will take many decades to flow through.

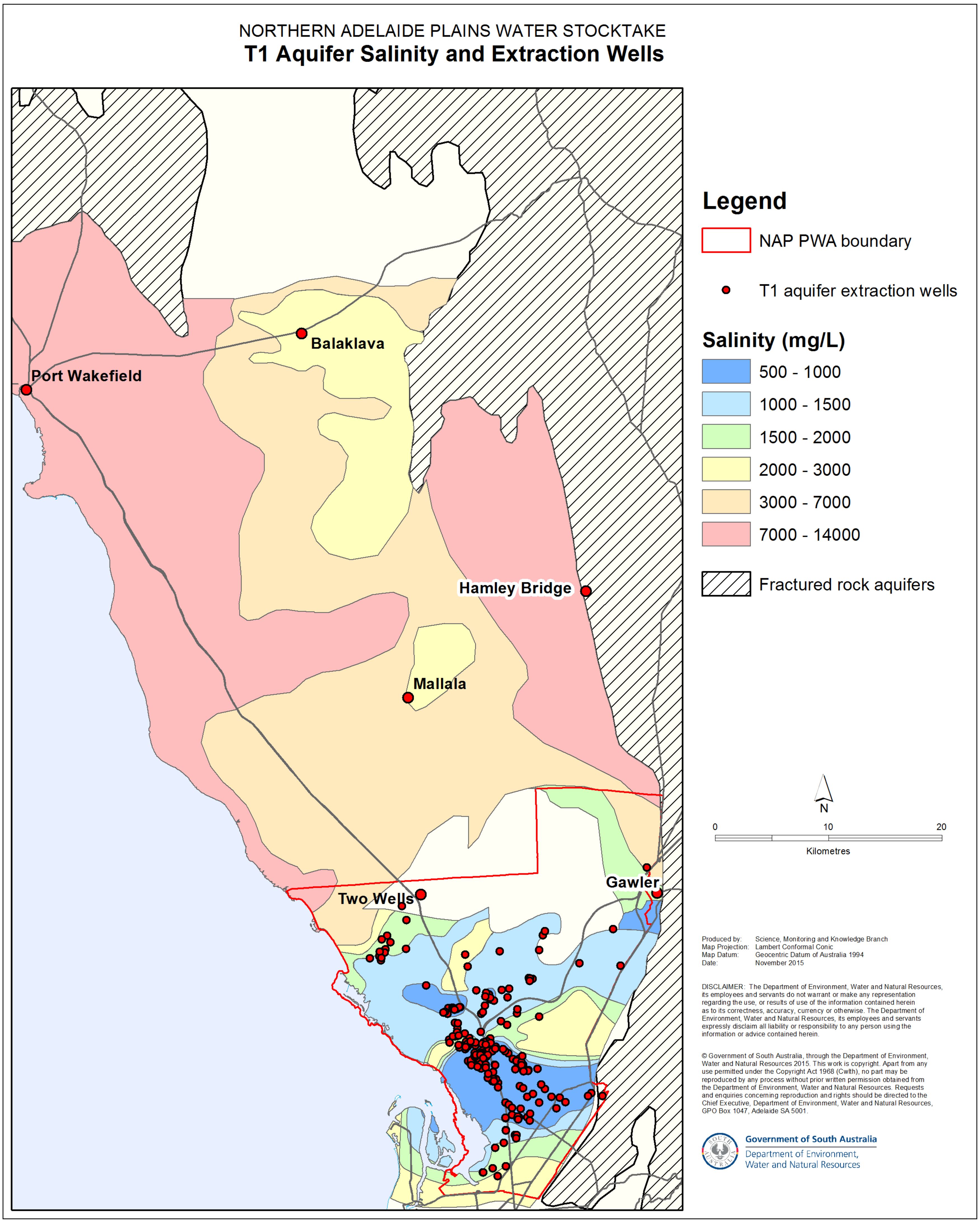

Figure 4.10. Location and salinity of T1 aquifer bores in the Northern Adelaide Plains and southern part of the Two Wells to Whyalla Regional Corridor (source: Goyder Institute 2016a).

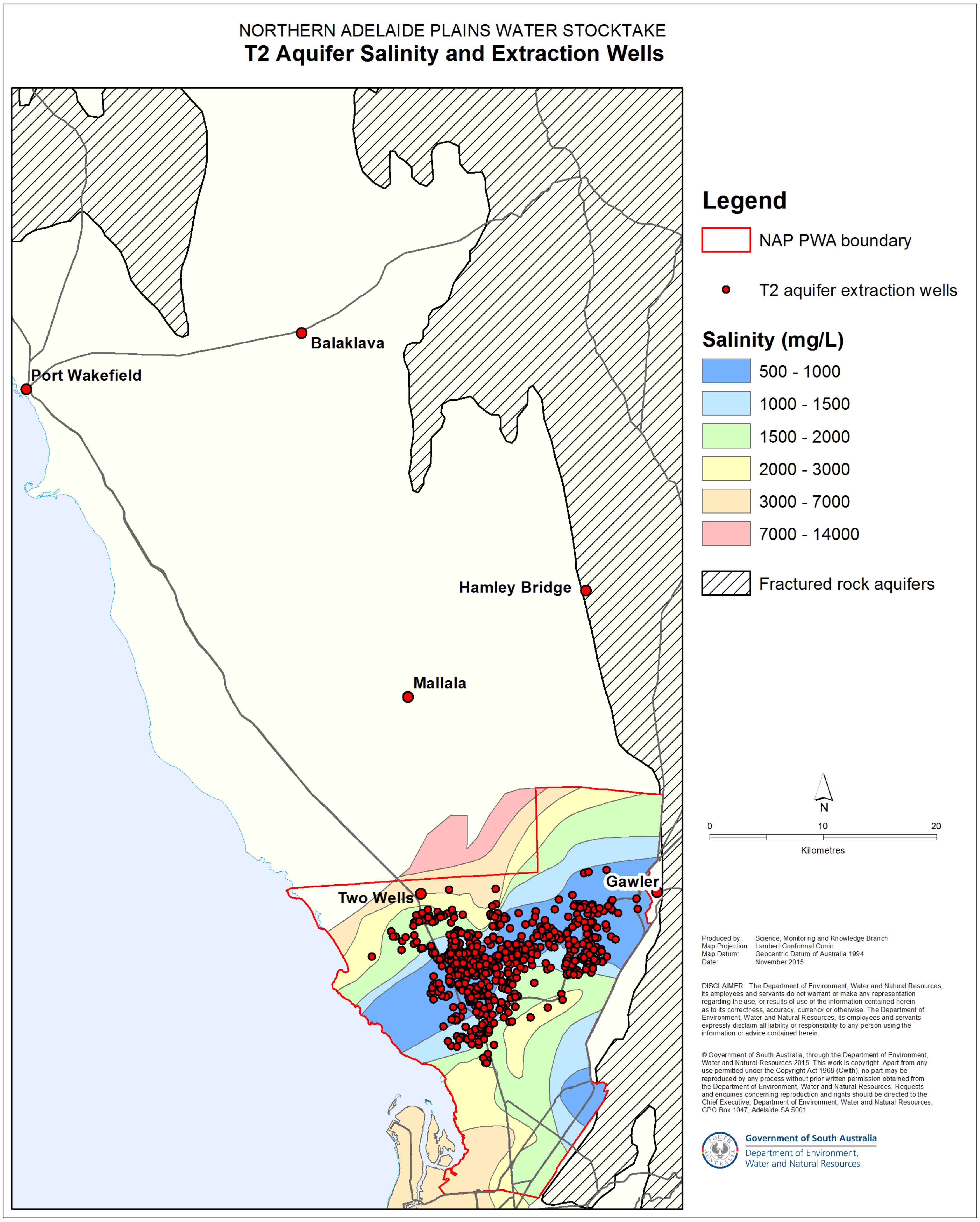

Figure 4.11. Location and salinity of T2 aquifer bores in the Northern Adelaide Plains and southern part of the Two Wells to Whyalla Regional Corridor (source: Goyder Institute 2016a).

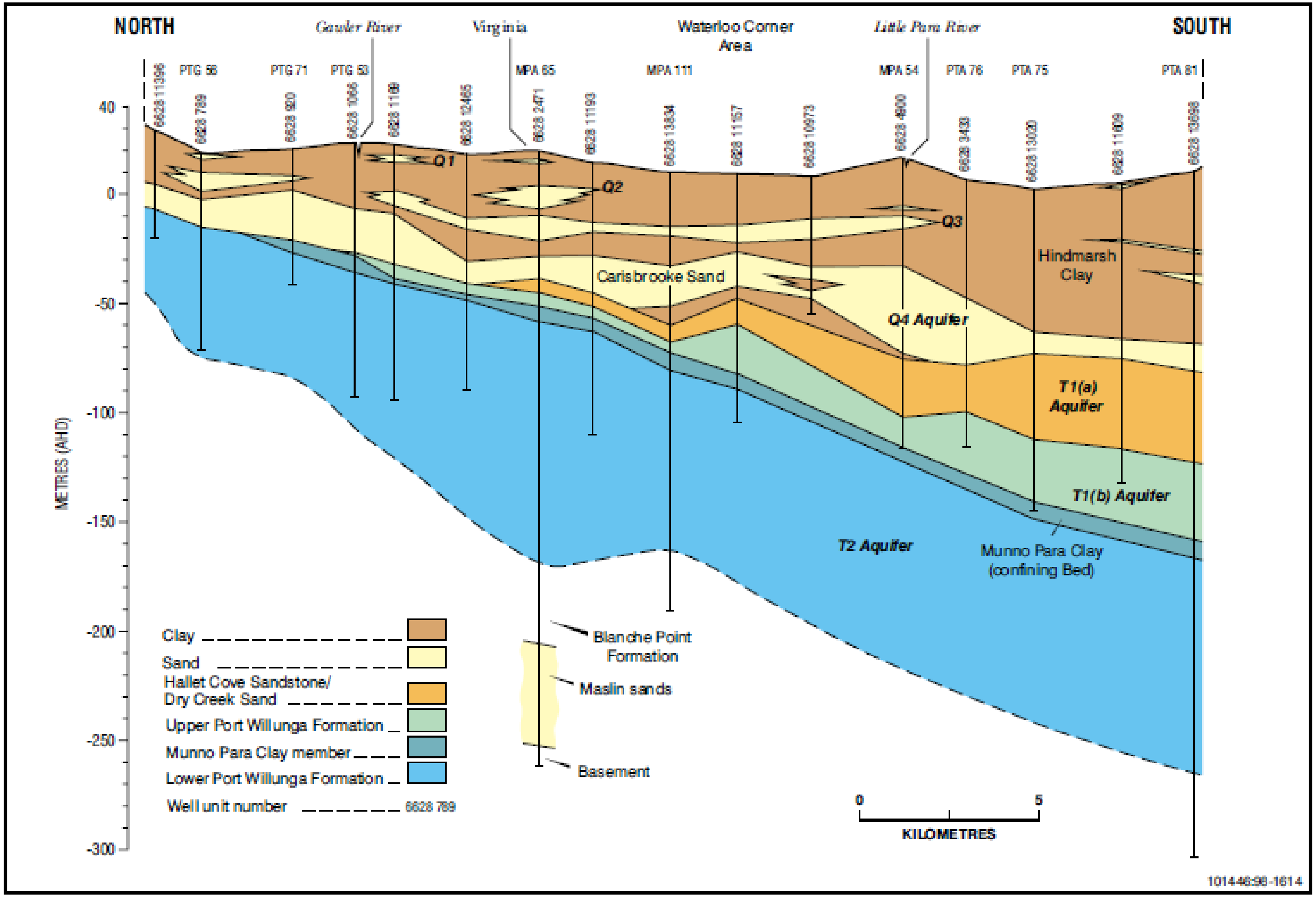

Figure 4.12. North-south cross section of the hydrogeology of the North Adelaide Plains showing the distribution and depths of the Quaternary aquifers, Q1-4 and Tertiary aquifers T1 and T2 (source: Goyder Institute 2016a).

4.3.3. Reticulated water

Within the N&YNRMR region most townships receive potable water from South Australian Water reticulation schemes. Within the 2W2W coastal plain the most important of these are the Swan Reach-Stockwell pipeline supplies water to Port Wakefield, and Kadina, Moonta and Wallaroo just to the north of Yorke Peninsula) and the Morgan-Whyalla pipeline (supplies most of the area north of these towns, including the cities of Port Pirie, Port Augusta and Whyalla) (Alcoe and Berens 2011). To the south, the metropolitan Adelaide potable water reticulation scheme extends supplies into the NAP.

In 2015/16 the sources of the potable water supplied by SA Water were 83.1% from the River Murray, 8.0% from surface water, 3.4% from desalinated seawater and 5.5% from groundwater (SA Water 2017). The water quality of potable reticulated water is carefully maintained by SA Water through catchment and reservoir management; use of 42 treatment plants to remove most hazards including sediments, metals, chemicals (including pesticides, hydrocarbons, iron and manganese), algal bioproducts and pathogens; disinfection with chlorine and chlorine residual maintenance; and use of closed systems and backflow prevention. In 2015/16, 99.96% compliance with the Australian Drinking Water Guidelines health related parameters, was achieved in metropolitan Adelaide and 99.83% in regional areas (SA Water 2017).

Of interest to aquaculturists is that the potable reticulated water provided by SA Water can approximate air temperature seasonally, has a low salinity (typically less than 0.5 ppt) and is of excellent quality for use with aquatic organisms except that the free chlorine levels, which while low (<0.1-3.9 mg L^{-1}) and within the aesthetic and health guidelines (<0.6 mg L^{-1} and <5 mg L^{-1}, respectively), can cause sub-lethal and lethal effects on aquatic organisms, especially if added to the organisms environment rapidly. SA Water (2017) provides the maxima and minima recorded for a wide range of water quality parameters for 2015/16 across much of South Australia.

South of 2W2W in the NAP, is the Adelaide metropolitan potable reticulation scheme as well as a number of reticulated recycled water systems, including the VPS, Managed Aquifer Recovery (MAR) Schemes and the North Adelaide Irrigation Scheme (NAIS). The latter has recently been funded and in 2018-19 will likely provide an additional 12 GL $annum^{-1}$ (60% increase) of high-quality recycled water, treated through the Bolivar WWTP and Bolivar Dissolved Air Flotation and Filtration Plant (DAFF), for an expansion of commercial food crop production in the NAP. Additional capacity will be built in to enable future expansion to 20 GL $annum^{-1}$ enabling an increase in irrigated farming further north into 2W2W around Two Wells.

Monthly water quality data for VPS effluent water is presented for 2012 to 2016 in Goyder Institute (2016a) and summarised in Adell (2017). The range for parameters of most interest to aquaculturists are: temperature (11-23°C), salinity (0.8-1.2 ppt), dissolved oxygen (3.4-13.4 mg L^{-1}), pH (7.8-9.4), median hardness (calcium carbonate; 227 mg L^{-1}), ammonia (0.1-0.9 mg L^{-1}) and phosphorus (0.16-0.79 mg L^{-1}), with only the latter two of potential concern to aquaculturists (Boyd 19). Comparison of the inorganic parameters monitored with the ANZECC (2000) guidelines reveals that the recycled water has aluminum concentrations that range from 0.001-1.90 mg L^{-1}, with the average of 0.13 mg L^{-1} well above the guideline value of 0.03 mgL^{-1}. Total copper, manganese and zinc levels are also slightly raised but should be satisfactory because the water hardness is greater than 100 mg $CaCO_3$ L^{-1}. It is notable that for many water quality parameters the maximum recorded values are well above the median for reticulated waters, whereas this is not nearly as apparent for groundwater, which is more consistent. SA Water pesticide and herbicide residue limits were not viewed for reticulated water, but advice received was that because the levels of detection of the analytical testing undertaken for a number of agricultural pesticides is above the recommended levels, it is uncertain whether these may or may not be of concern.

The range for total and free chlorine concentrations for recycled water is reported, respectively, as 0.866-3.825 mg L^{-1} and 0.2-2.875 mg L^{-1} with the average of each, 1.841 and 0.939 mg L^{-1}, well above the guidelines <0.003 mg L^{-1}, making it less than ideal for aquaculture unless treated (e.g. aeration).

4.3.4. Gulf St Vincent marine waters

Gulf St Vincent is a semi-enclosed, inverse estuary (salinities increasing with distance from the ocean due to low freshwater inflows and high evaporation) marine embayment of about 6,800 km^2 and with a north-south length of 120 km and depths of less than 50 m. To its south lies Kangaroo Island with Investigator Strait and Backstairs Passage connecting it with the Southern Ocean. It has a tidal range of about 2.2 m, has a shallow more gradually sloping east coast, experiences two high and two low tides daily, and is relatively unique (like Spencer Gulf) in having a dodge tide event where there is little tidal movement every two weeks. At Middle Beach, the south-western extent of 2W2W, St Vincent Gulf is about 45 km across to Port Julia, Yorke Peninsula and has a maximum depth of 25 m. From here north, significant wave heights decline rapidly from about 0.5 m, with the coast progressing from one of moderate to low wave exposure. General annual circulation in the gulf tends to be northward along the west coast and southwards along the east coast (Bye and Kampf 2008).

Water temperature is largely controlled by air temperature and water depth. In the gulf, mean daily sea surface temperatures and salinities range, respectively, from about 12.0°C and 36 ppt in August to about 26.0°C and 42 ppt in February (Edyvane 2008). In the very shallow coastal waters adjacent 2W2W, where pipelines for aquaculture might intake water, water temperatures and salinity ranges are likely to be more extreme.

4.3.5. Spencer Gulf marine waters

Spencer Gulf is a semi-enclosed, inverse estuary (salinities increasing with distance from the ocean due to low freshwater inflows and high evaporation) marine embayment of about 21,125 km^2 and with a north-south length of 325 km and depths of less than 50 m (Nunes-Vaz 2014). To its south lies the Southern Ocean. It has a tidal range of about 2.0 m at Port Lincoln and Wallaroo and nearly 4 m at Port Pirie, Whyalla and Port Augusta; has a shallow more gradually sloping east coast; experiences two high and two low tides daily; and is relatively unique (but like Gulf St Vincent) in having a dodge tide event where there is little tidal movement every two weeks. At Wallaroo, the south-western extent of 2W2W on the coast of Spencer Gulf, the gulf is about 60 km across (to Cowell, Eyre Peninsula) and has a maximum depth of about 25 m. From here north, significant wave heights decline rapidly with the coast progressing from one of moderate to low wave exposure. General winter circulation in the gulf tends to be northward along the west coast as water flows into the gulf to replace the high salinity water that moves southwards along the east coast, forming gyres along the way. In summer a thermocline often forms at the bottom of Spencer Gulf preventing the entry of oceanic water (Kampf 2014).

Water temperature is largely controlled by air temperature and water depth. In the gulf, mean daily sea surface temperatures and salinities range from winter to summer, respectively, from about 12.4-22.8°C and 38-40 ppt at Wallaroo, to about 11.6-25°C (winter-summer) and 43-49 ppt at Port Augusta (Kampf 2014). In the very shallow coastal waters adjacent 2W2W, where pipelines for aquaculture might take-in water, water temperatures and salinity ranges are likely to be more extreme (e.g. the Port Augusta Power Station inlet/outlet).

Water residence time in northern Spencer Gulf is greater than one year indicating little mixing of the water (Kampf 2014), which is important when considering the interaction of any aquaculture development bringing in or discharging water to the marine environment. A long residence time mean that wastewater discharges are more likely to impact on the general environment, other users of the environment and even on the aquaculture venture itself.

4.3.6. Water costs

Water costs associated with surface and groundwater supplies, besides licencing costs, are related to energy costs associated with pumping the water. Due to the large diversity of pump types, power types (e.g. electricity, fuels - biogas, diesel, solar, wind or some combination of these), the pressure that the water is under, the pumping head involved, and a number of other variables it is not possible to estimate an indicative price.

SA Water's pricing (https://www.sawater.com.au/my-account/water-and-sewerage-prices/water-prices) in 2017/18 for potable reticulated system water for country land outside town boundaries, including broad-acre farming land (i.e. non-residential and non-commercial use) comprises a fixed charge for water supply of $73.10 per quarter and a variable charge based on water use of $3.308 KL^{-1}. For commercial use (e.g. retail and wholesale trade) the fixed price component is charged at $0.17525 per $1,000 of property capital value with a minimum charge of $73.10 and again a variable charge of $3.308 KL^{-1}.

SA Water's 2017-18 pricing for sewerage is $0.457 per $1,000 of property capital value, with a minimum charge of $78.35 per quarter.

SA Water's 2017-18 pricing for VPS recycled water is also based on supply and usage charges (Goyder Institute 2016a). An annual fee of about $1,220 is charged per customer for up to three connections, then charged at the same rate per connection thereafter. VPS water usage is then charged on a tier system based on the season of the year: spring – $0.122 KL^{-1}, summer – $0.154 KL^{-1}, autumn – $0.122 KL^{-1} and winter – $0.813 KL^{-1}.

4.4. Potential aquaculture sites

4.4.1. Whyalla to Port Augusta and inland

Potential exists for some additional land-based, hypersaline, pond aquaculture (e.g. microalge) and possibly RAS in close proximity to the city of Whyalla, Point Lowly and Port Bonython, as well as options for land-based services for sea-based aquaculture development in Fitzgerald Bay. While there is relatively cheap land away from the sea and the city is an industrial one with good levels of infrastructure, labour and transport, little information was located in relation to groundwater supplies for aquaculture use, other than there are relatively few bores in the area. There was no information on groundwater water temperature and water quality.

Coastal seawater in the area is typically very saline (>38 ppt) and varies considerably in temperature seasonally, neither which are desirable for many types of aquaculture. Seawater is also likely to be difficult to access and discharge by pipe in most areas due either to the existence of port facilities with their less than desirable water quality (some industrial pollution from the steel works and the potential for spills from the loading of vessels at Port Bonython) and broad beaches, cliffs and other developments in the proximity of the coast in some areas making access, pumping distances and/or pumping heads an issue. The offshore sanctuary zone centred on Black Point also potentially limits discharges, with the coastal native vegetation limiting land disturbance associated with construction.

From Fitzgerald Bay north to Port Augusta, the Cultana Training Range occupies almost all the land within 2W2W, except for a narrow coastal strip with small, relatively narrow sand beaches between low relief rocky headlands, with a deeper channel close offshore on this, the western side, of the gulf; all characteristics suitable for piping seawater to an onshore aquaculture operation. While the area also has little habitation (a few areas of beach shacks), it also has limited infrastructure services and is popular for recreational use. The marine environment in this area is a habitat protection zone and about midway along and abutting the coast, is the Blanche-Harbour – Douglas Bank Aquatic Reserve, which is a sanctuary zone. Coastal seawater in the area is typically very saline (>40 ppt) and varies considerably in temperature seasonally, neither which are desirable for many types of aquaculture. The few bores in the area for which any data exist (Figures 4.7, 4.8 and 4.9) typically have high salinities of 6-20 ppt, moderate to deep standard water levels of 20-173 m and low yields of <1 Ls^{-1}, although a few about 2 km northwest of the northern extent of Fitzgerald Bay (Water Connect SA 2017), have maximum depths of 10-12 m and a surprisingly low salinity (0.4-0.5 ppt). No information was, however, located on their water temperature or other water quality parameters important for aquaculture. While PSM (1998) suggest pump-ashore land-based aquaculture might be feasible in this area, it is the opinion of the author of this report that no land-based aquaculture development is likely, unless it can be aligned with the establishment of a much larger, complementary development such as a pumped hydro energy system (PHES), which would require access to land, power, transport and water.

The city of Port Augusta, like Whyalla, has appropriate infrastructure, services and land, but with water access to the gulf limited by the marine sanctuary zone to the north of the city and the land adjacent the waterfront where the power stations used to be held by an aquaculture company (although not using the hatchery and ponds present), little opportunity for aquaculture is considered to exist. The few bores in the area for which any data exists (Figures 4.7, 4.8 and 4.9), display decreasing salinity with depth, those with a standard water level of 1-2 m having a salinity (TDS) of 65-106 ppt and one at 24 m having a salinity of 10 ppt and yield of 0.9 Ls^{-1} (Water Connect SA 2017). Pump-ashore aquaculture would need to be of a type that can address the high salinities (>45 ppt at times) and seasonal extremes of temperature (e.g. 11-28°C) of the gulf waters in this area, with pond-based hypersaline aquaculture of algae and/or brine shrimp the more likely. Another opportunity might be for a RAS or hatchery-based aquaculture venture aligned with Sundrop Australia's green-house based horticulture operation that obtains its freshwater from desalinated seawater and energy from a thermal solar system (http://www.sundropfarms.com/).

4.4.2. Port Augusta to Port Pirie and inland

The coastal area is not considered likely for pump-ashore aquaculture development because of its high conservation value, signified by the presence of the Winninowie Conservation Park on land and Yatala Harbour and Chinaman Creek sanctuary zones in the gulf. Gulf waters, as on the western side, are highly saline and fluctuate greatly in temperature seasonally, but here with a very gently sloping coastline, are even less ideal for accessing seawater. Also, from just north of Port Pirie north to Waroona Island is a large wide beach area that is popular with recreationalists.

Bore water (Figures 4.7, 4.8, 4.9) in the north tends to be of higher salinity adjacent the coast (>20 ppt) and lower salinity inland at the base of the Southern Flinders Ranges (<1.5 ppt). The bores of higher salinity typically have a shallow standard water level (<10 m) and low yields (<1 Ls^{-1}) compared to those of lower salinity, which typically have a deeper standard water level (20-50 m) but still low yield (<1 Ls^{-1}). Southwards towards Port Pirie the narrow coastal plain has more suitable groundwater with the lowest salinities (<1.0 ppt) and highest yields (5-10 Ls^{-1}) in the Baroota PWRA where maximum depths are shallowest towards the coast and deepest towards the ranges. No information was located on groundwater temperatures or water quality parameters of interest to aquaculturists.

Port Pirie and vicinity is impacted by lead pollution and this should be a major consideration if utilising seawater that might include disturbed marine sediments, constructing onshore facilities that will disturb or lead to surface soil contact, or access shallow groundwater.

In summary, freshwater RAS aquaculture is considered feasible in parts of this area, with the best opportunities for freshwater aquaculture in the Baroota PWRA, but water would need to be accessed from an existing licensee using it for agriculture/horticulture. External to the PWRA, freshwater and brackish water RAS aquaculture is likely to be feasible at select locations.

4.4.3. Port Pirie to Port Broughton and inland

From Port Pirie south to Port Davis (where a jetty exists) and Point Jarrold (about 20 km west southwest) the coast has a very gradual slope and is dominated by a mangrove community dissected by multiple small tidal creeks, a couple with boat ramps for use by recreational fishers. Seaward of the mangroves are mud flats and then seagrass beds, while inland is native vegetation. While the coastal land is state government owned or freehold farming land, the coastline is far from ideal for accessing and discharging seawater and may be influenced to a slight degree by pollution for Port Pirie. As such, this area is not considered desirable for aquaculture development, although earlier studies by PSM (1998) and AGC (1989) suggested that semi-intensive pond culture and RAS might be feasible in this area.

South of Point Jarrold to Fisherman Bay the coast is more wave exposed and seaward has wide seagrass beds (1-2 km) and a wide intertidal sand area (1-2 km) backed by coastal dunes and salt pans (1-2km); landward of this is freehold farmland. The broad coastal expanse makes pump-ashore seawater aquaculture challenging and as such is not considered likely for aquaculture development.

Fishermans Bay, just to the north of Port Broughton, is a largely enclosed, shallow and seagrass filled, with a significant residential and visiting fisher community. It is not considered suitable as a location for pump-ashore aquaculture.

Inland in this region there are few groundwater bores other than along a west northwest – east southeast line which stretches from Fifth Creek near Point Jarrold to Crystal Brook near the western margin of the Southern Flinders Ranges. Typically, borewater along this drainage watercourse have salinities (TDS) of 6-12 ppt, a standard water level of 0-5 m, and yields of <1 Ls^{-1} (Figures 4.7, 4.8 and 4.9).

In summary, this area is not considered a likely area for aquaculture development.

4.4.4. Port Broughton to Moonta and inland

Tourism has been the focus of the Port Hughes - Moonta – Wallaroo area in recent years, with farming and commercial fishing of traditional importance. Aquaculture is also a feature, with a zone presently designated primarily for bivalve mollusc farming offshore of Port Broughton and finfish and other multi-trophic species in a zone offshore and slightly south of Wallaroo. A land-based aquaculture prawn venture existed just south of the entrance to the largely land-locked Mundroo Bay. The past development comprised about 25 ha of land divided into two small ponds associated with seawater entry and exit, four medium size ponds and one very large pond. These continue to exist, although only the first two have water in them. Seaward of this aquaculture area exists a mangrove zone and seaward of the mangroves a seagrass zone. This area with its historic aquaculture use, flat land, existing access to seawater and closeness to Port Broughton is considered suitable for semi-intensive aquaculture development, with RAS also feasible but probably too remote from a major population centre and markets to be ideal. Matters of concern, are that seawater would be accessed from a narrow shallow channel between shallow offshore waters and a largely enclosed bay inshore; this is likely to result in seasonally variable water temperatures and salinities, and during heavy rainfall potential intake of waters affected by agricultural run-off, including a possible higher nutrient and agricultural chemical load.

From the past prawn farm south to the small township of Tickera, the coast has a wide intertidal sand area, backed by a narrow dune and natural vegetation area, with a broad seagrass zone offshore. Further south from Myponie Point to Point Riley, wave exposure increases and the coast comprises small beach areas, one occasionally with a shack, interspersed between headlands. The subtidal zone in this region is characterized by extensive areas of rocky substrate that transform into seagrass beds at about 2-3 m depth and continue offshore to a depth of about 15 m. The beaches are backed by a 3-5 m rise to farmland, with a vehicle track (Myponie Point Drive) along most of this coastline. As such, the farmland nearest the coast is only some 100-200 m from the water, with the seawater well mixed and pristine. In the late 1980s this area was investigated by Kinhill Stearns for development of a power station, with a comprehensive examination of the coastal region for access and discharge of cooling water.

The coast south of Point Riley to Moonta is not ideal for sourcing seawater for pump-ashore aquaculture due to the townships of Wallaroo, Moonta and Port Hughes; an area of cliffs; Warburto Point and the Bird Island Conservation Park with their mangrove and samphire flats; and a number of wide beaches used recreationally by the people of this areas as well as visitors.

Inland of Port Broughton to Moonta there are relatively few groundwater bores. They only become common in the higher relief Hammock Ranges north of Port Wakefield and further west around Snowtown (Figures 4.7, 4.8 and 4.9). At Tickera there are a few bores near the coast with salinities of 24-35 ppt for standard water levels of 34-72m and yields of 0.3-1.3 Ls^{-1} (Water Connect 2017). About 10 km inland there is a shallow bore at a standard water level of <10 m that has a salinity of <1.0 ppt and a yield of <1 Ls^{-1}. At Wallaroo the groundwater shows a similar pattern as to Tickera. As there was large scale historical copper mining in the Wallaroo to Moonta area, heavy metal contamination of groundwater should be considered prior to its use.

In summary, the old prawn farm site just south of Port Broughton and the Myponie Point to Point Riley area between Tickera and Wallaroo are considered to provide suitable locations for pump-ashore aquaculture development, both pond-based semi-intensive and RAS. RAS aquaculture would also be feasible in some places inland, but further research to determine water temperature and quality would be recommended.

4.4.5. Port Wakefield to Middle Beach – Two Wells and inland

Pump-ashore aquaculture is notconsidered feasible for the east coastline of Gulf St Vincent from the northern limits 10 km north of Port Wakefield south to Middle Beach, because of the existence of the Clinton Conservation Park, Australian Department of Defence Port Wakefield Proof and Experimental Establishment Proof Firing Range. It is also not considered feasible further south due to the high conservation significance of the coastal plant communities (i.e. samphires, mangoves, cyanobacteria mud flats and seagrasses) and associated animal species (particularly birds and aquatic animals) if lengthy pipelines are required to access the low lying, salt pan and freehold farm land adjacent to Thompson Beach, Webb Beach, Port Parham and slightly north as their construction would disturb the environment. If, however, seawater could be cost effectively accessed by the use of shallow coastal saltwater bores or pits landward of these plant communities, then this land might be suitable. No data were located as to the feasibility of such seawater intakes in this area.

Just south of 2W2W, the coastal area was once occupied by the Dry Creek Salt Fields. The first northern pond in the series (designated XE 1-3) is 170 ha in area and supplied with seawater from Chapman Creek. It offers potential for extensive and/or semi-intensive pond aquaculture and/or RAS, although the aquaculture undertaken would need to be complementary to slightly hypersaline waters that vary in temperature considerably over the seasons. It would also be important to ensure that wastewater discharges from the Bolivar Sewage Treatment Works to the south do not detrimentally affect the product quality of the aquaculture produce.

The groundwater in the Port Wakefield to Middle Beach – Two Wells and inland region varies considerably in quality and quantity (Figures 4.7, 4.8 and 4.9). To the east of Port Wakefield salinity increases from about 3-7 ppt to 7-12 ppt and above. In a small area around Balaklava and along the Wakefield River there are salinities <1.5 ppt. Farmers in the past used bores sunk to 20-33 m depth but subsequently deeper wells were established. One of particular notice, is at the Balaklava Golf Club (Anon 1991), which has a bore with a salinity of 2.1 ppt, a standard water level of 61 m deep, a yield of 15 Ls^{-1} (nd a pH of 7.5. No information was located in relation to water temperature or of water quality parameters of interest to aquaculturists.

5. Potential Opportunities

5.1. Recirculation aquaculture systems

Strong consideration of the use of RAS is recommended for 2W2W for five primary reasons:

1. the capacity of RAS to maintain water temperature year-round at the optimum required for aquaculture species production and feed conversion;
2. biosecurity and security;
3. the potential for freshwater RAS to be incorporated directly (aquaponics) or indirectly (downstream utilisation of waste nutrients and water) with hydroponics, which is common in the region;
4. environmental sustainability; and
5. the substantial improvements that have occurred to RAS over the last 5-10 years that has improved their economic viability.

However, the commercial viability of RAS with any of the recommended species within or nearby 2W2W is unproven, except for Barramundi. Worldwide, even for Salmon, a species that has been farmed in RAS since the late 1980s, the majority of production from this type of system is less than 0.5% of total production. Also, most of this production is based only on the growth of this species from the fertilised egg or fry stage to the smolt life stage, in contrast to growing fish through to harvest for marketing to consumers.

For more information on RAS technologies and their application, see Bregnballe (2015), DNB (2017) and Neomar (2014).

5.1.1. Recommended species

Barramundi and salmonids are the obvious choice for intensive RAS in Australia (the latter less so in the 2W2W region of South Australia due to their need for cooler water temperatures) as they are finfish species that have been farmed globally in such systems for some years (primarily in China, Europe and the USA). There is much known about these species from a biological and engineering perspective, although little of this has been published and few people have relevant practical experience. Barramundi and salmonids are also an obvious choice because of the existence of hatcheries for these species and their well-defined supply chains and markets. Despite these advantages, it should be noted that many overseas start-ups using these species have failed.

In Australia, there are few intensive RAS in operation producing native Australian finfish species from the hatchery to growout stage, and those that exist (e.g. for Barramundi) are a small, and having typically been constructed in the mid-1990s, are based on outdated technology. As such, there is a paucity of comprehensive information relating to the culture of novel native Australian species of most interest for RAS cultivation for 2W2W: Murray Cod (a freshwater species) and Yellowtail Kingfish (a marine species).

5.1.2. Financials of Recirculation Aquaculture Systems (RAS) aquaculture

Obtaining realistic figures of the construction and production costs for commercial RAS operations for any species is challenging because of the commercial sensitivities of such data and its dependence on a wide range of biological, environmental, engineering and local service costs. What is available is primarily on Salmon aquaculture, which is the most common form of aquaculture in these systems. Some information exists for other species such as Barramundi (e.g. Hutchinson et al. 2004, Bijo 2007), Mulloway (Econsearch 2008), Murray Cod (Rawlinson 2004) and Yellowtail Kingfish (Musely and Goodwin 2012), although all of these except Hutchinson et al. (2004) have been produced by researchers using models based on hypothetical commercial operations.

What becomes readily apparent from the literature is that RAS vary greatly in complexity and thus construction and operating cost. At the lower end, aquaculturists have established their own systems made from individual components they have sourced from various supply companies and put together, sometimes even within converted buildings sourced at little cost when their original use ended. Alternatively, systems can be provided as complete systems (i.e. turn-key operations) by companies recognised globally for their many years of experience in the design, construction and operation of RAS (e.g. Billund Aquaculture). Other companies work with clients to provide whatever level of support they require, from the sale of individual RAS components to a partial or full advisory service addressing, design, construction and operation (e.g. Pentair).

Due to the challenges in obtaining accurate financial modelling for 2W2W RAS production for the preferred species, the estuarine Barramundi, freshwater Murray Cod and marine Yellowtail Kingfish, information presented here firstly addresses RAS production of Salmon as this provides useful background information for comparison with what is subsequently provided addressing the species of interest.

5.1.3. Salmon Recirculation Aquaculture Systems (RAS)

RAS information and financial figures for Atlantic Salmon culture have been provided by Patrick Tigges, Billund Aquaculture for two production scales: 1,000 and 3,000 tonnes annum^{-1}. The former is considered a good target size as it will generate some economies of scale and is fairly typical of current international commercial RAS size, while the latter is used to demonstrate that further economies of scale can be achieved. It should be noted that while the 3,000 tonnes annum^{-1} production system might seem large, is not an unrealistic target given that there are now a number of RAS systems of 10,000-20,000 tonnes annum^{-1} production under development, with expansion plans to reach 33,000 (i.e. Nordic Aquafarms, Maine, USA) and 90,000 tonnes annum^{-1} (i.e. Langsand Laks, Jutland, Denmark). Information listed in tables below is indicative of typical costs in 2016/17 and should be used as a guide only.

Table 5.1: Cost summary for typical stage 1 of a project, the design, drawings for concrete construction, supply of equipment and piping, installation of piping and equipment, commissioning, test, handover and technical and operational training for a 1,000 tonnes annum^{-1} Atlantic Salmon RAS; €1 = Au$1.52)(source: Billund Aquaculture).

Quantity	Description	Total price (€)	Total price (Au$)
2	Hatchery	138,800	210,778
1	Starter feeding system	188,400	286,099
1	Fry/smolt system	493,500	749,279
1	Post smolt system	1,452,700	2,205,628
1	Ongrowing system	3,200,800	4,859,276
1	Off flavour rectification system	266,300	404,282
1	Grading pipes	161,700	245,489
1	Grading equipment	269,900	409,755
1	Treatment of intake water (freshwater)	55,700	84,562
1	Treatment of intake water (seawater)	150,200	228,053
1	Temperature regulation	450,000	683,248
1	Lights for fish tanks	154,000	233,823
1	PC monitoring system	61,000	92,618
1	Training package – 6 months	75,000	113,875
1	Sludge thickening system	113,400	172,179
Total Price ex Billund Aquaculture, Denmark		**7,231,400**	**10,980,447**

The smaller Billund Aquaculture Salmon RAS, as presented here, is based on buying eggs from an external supplier and producing 1,000 tonnes annum^{-1} of 4.5-5 kg live weight of salmon annum^{-1}. It consists of a system comprising seven components: two hatcheries, one starter-feeding system, one fry/smolt system, one post smolt system, one growout system and one off-flavour depuration/rectification system, which with their purchase prices are presented in Table 5.1. The 3,000 tonnes annum^{-1} RAS is similar but larger, with three growout system components.

Billund Aquaculture, like most other large RAS construction companies, provides design, drawings for concrete construction, supply of equipment and piping, installation of piping and equipment, commissioning, testing, handover and technical and operational training (i.e. a ‘turn-key’ facility). The plant is delivered complete and tested with water, a one-year warranty is provided from the date of commissioning along with a 24 hour help hot-line. Connection to the Programmable Logic Controller (PLC) is possible by remote internet access facility, and training and education of staff at all levels is provided for a period of six months and includes start-up and then the life cycle of the fish from egg to harvest size.

Billund Aquaculture, like many other turn-key RAS providers, does not address all aspects of construction, which is an important consideration for the customer. Typically, the customer must organise and pay separately for all permits; valuations; site excavation work and lowering of water table if necessary; construction of the building including foundations and floors; insulation of the building; installation and wiring of the building ventilation system; complete concrete works for installation of RAS equipment; electrical engineering and electrical design/dimensioning and installation; internet connection; access to water, electricity and toilets during the construction period; removal of packaging, stormwater and sewer piping; offices and equipment; laboratory equipment for testing water quality; installation and wiring of emergency generator; oxygen generator and cryotank for oxygen; fish tanks; nets for harvesting and ‘jump fences’; piping and supply of freshwater, seawater and tap water to the system; cleaning and disinfection of the system after installation; piping outside building to discharge point; buffer tank for sludge/discharge water; storage tank for sludge; silo for lime, control feed system; fish grading equipment; fish therapeutic equipment; crane for off-loading and installation of equipment on site; accommodation for Billund Aquaculture staff during construction; four skilled workers to work with Billund Aquaculture staff during the construction period; a car for Billund Aquaculture staff; an office on site with furniture for two Billund Aquaculture personnel; 200 m^2 roofed storage area with floor for Billund Aquaculture tools and equipment; uncovered area for storage of equipment; and transport for Billund Aquaculture staff from airport to construction site.

The Billund Aquaculture 1,000 tonnes annum^{-1} Atlantic Salmon RAS production plan and the size of the facility is based on an input of five batches of Salmon annum^{-1}, each batch consisting of about 60,000 eyed eggs from an external supplier. The 3,000 tonnes annum^{-1} production plan is also based on an input of five batches of Salmon annum^{-1}, but in this case with each batch consisting of about 180,000 eyed eggs. The production cycle of both Billund Aquaculture production size RAS are advised to take 92 weeks (~650 days) after the eggs hatch, with Salmon weighing about 0.25 kg at 32 days, about 1.5 kg at 64 days and 4.5-5.0 kg, the harvest size, after 650 days.

The estimated investment and operating costs for Salmon growout to 4.5 kg harvest weight for the 1,000 tonnes annum^{-1} RAS are, respectively, \$24,506,063 and \$3,231,111 and for the 3,000 tonnes^{-1} RAS, \$58,161,052 and \$8,169,299 (Table 5.2). Some economies of scale are evident as production amount increases, both in relation to the capital costs and operating costs.

Table 5.2: Estimated investment and operating costs for Atlantic Salmon growout to 4.5 kg harvest weight (€1 = Au\$1.52) (source: Billund Aquaculture).

	1,000 tonnes annum^{-1} (5 fish batches)	3,000 tonnes annum^{-1} (5 fish batches)
Investment costs		
Buildings	4,458,997	9,323.7
Electrical installations	991,636	2,171,100
Other installations (ventilation, etc)	822,992	1,609,600
RAS equipment (Billund Aquaculture to supply)	7,231,400	16,835,000
Concrete work (RAS & fish tanks)	2,077,717	7,575,750
Various	539,667	748,700
Total investment	**16,122,410 (Au\$24,506,063)**	**38,263,850 (Au\$58,161,052)**
Operational costs (first year of harvest)		
Maximum biomass (kg)*	444.0	1,382,100
Value of Biomass	1,056,145	3,304,153
Staff**	460,000	620,000
Sludge	44,400	138,210
Environmental inspections	50,173	150,000
Veterinarian	44,400	138,210
Chemicals	13,320	41,463
Denitrification	35,520	0

Phosphorus removal	8,880	0
Oxygen vessel rental	8,000	8,000
Maintenance	322,448	765,277
Insurance of biomass	17,954	56,171
Insurance of buildings and technical installations	64,490	153,055
Total operational costs	**2,125,731**	**5,374,539**
Operational cost (first year of harvest)	2,125,731 (Au$3,231,111)	5,374,539 (Au$8,169,299)
Total investment excluding egg production	16,122,410 (Au$24,506,063)	38,263,850 (Au$58,161,052)
Total investment including operational costs (first year of harvest)	**18,248,141 (Au$27,737,174)**	**43,638.389 (Au$66,330,351)**

*Comprises 25,800 kg of smolt and 1,356,300 kg ongrowing fish

**Staff includes 1 x Production Manager, 1 x Engineer, 1 x Administration/financial Officer, 8 x Part-time Farm Workers

5.1.4. Yellowtail Kingfish Recirculation Aquaculture Systems (RAS)

As part of a feasibility study of land-based aquaculture in New Zealand (Musely and Goodwin 2012), economic modelling was undertaken for the ten most promising species identified: Rainbow Trout (most promising); King/Chinook Salmon; Yellowtail Kingfish, the species of interest for 2W2W; Abalone/Paua; Hapuka/Grouper; Ornamental and Aquarium trade species; Silver/Grass Carp; Short-finned Eel; Watercress; and Koura, a New Zealand freshwater crayfish (least promising).

Musely and Goodwin (2012) indicated that the economic model they developed used the best available scientific data on the optimum environmental parameters for growth (e.g. temperature, feed and oxygen) and water quality (e.g. carbon dioxide, ammonia and particulate matter), and from these calculated both the infrastructure requirements (capital costs) and operational costs of farming stock from fingerlings to market size. As such, their economic models provide the user with an indication of the likely costs of establishing and running a land-based aquaculture venture for the selected species. They also enable the user to manipulate a number of variables, particularly those relating to the scale of production, growth rates, key operational costs and market value, thereby enabling the user to determine the effect/sensitivity of these manipulations on such key economic feasibility indicators as the cost of production (CoP), level of investment, finance level, the net present value (NPV) and internal rate of return (IRR).

The hypothetical Yellowtail Kingfish farm of Musely and Goodwin (2012) consisted of two separate juvenile rearing and two separate ongrowing systems, each of these being in a separate room and having a separate recirculation and reticulation system to maintain water quality (e.g. ozone treatment, drum filters, biofilters and oxygenation) while also enhancing biosecurity. The rearing systems for juvenile fish, stocked at 5 g and transferred to the growout system at 250 g, comprised ten 10 m diameter by 2 m deep circular tanks. The growout system comprised twenty 20 m diameter by 3 m deep circular tanks to grow the fish from 250 g to a market size of 3,500 g. To house these systems, a building of about 130 m x 150 m was required, ideally situated on at least 7,000 m^2 of land so that there is space for such things as access, equipment and feed storage, and water delivery, discharge and wastewater treatment. System water volume is estimated at about 23,000 KL, which with 95% recirculation would require 1,150 KL day^{-1} or about 800 L min^{-1}. Stocking density would average between 50-80 kgm^{-3}.

Stock management within the RAS farm is critical for efficiency and to ensure regular supplies for marketing. Ideally the farm would be stocked monthly but more typically it is likely to be quarterly (most existing Yellowtail Kingfish hatcheries produce eggs and fingerlings from about August-February as their cycle is aligned to the stocking of sea cages, which typically occurs about four times between spring and autumn in alignment with warmer seawater temperatures). As fish do not all grow at the same rate, they are graded and at each grading event an opportunity exists to redistribute the fish between tanks so that fish of uniform size are kept together to facilitate optimal feeding and harvesting practices, the latter important for providing a continuous supply to market (critical for maintaining markets).

Using Musely and Goodwin's (2012) model for Yellowtail Kingfish, a best-case cash flow table was generated based on a 1,000 tonnes $annum^{-1}$ RAS production facility, which incorporates fingerling rearing and growout to market size, but not a broodstock holding facility or hatchery. The data entered for each variable that could be manipulated was that supported by the relevant scientific literature and/or word-of-mouth from knowledgeable industry representatives and researchers.

The output of the Yellowtail Kingfish model (Table 5.3) demonstrates that the capital cost of a 1,000 tonnes $annum^{-1}$ RAS for Yellowtail Kingfish is about NZ$11.5 million (AU$10,560,303), with the majority of the expenditure in the first year, but also some additional expenditure in Year 2 and then in Year 10 and 20, when various equipment will need replacement. The major capital costs identified are the buildings (43%), components of the recirculation system (40%), and water intake/supply system (9%), which can vary considerably depending on the system required (e.g. pumped from the sea or from a saline groundwater bore). Operating expenditure is relatively low in the first year, triples in the second year and then stabilises at NZ$9.6-12.0 million $annum^{-1}$ (AU$8,8-11.0 million $annum^{-1}$)

from Year 3 to 10. Operating expenditure is primarily associated with feed (43%), power (20%), staff (11%), fingerlings (10%) and the processing of the harvested product (9%).

For this scenario, NPV and IRR for year 10, 20 and 30 are respectively: NZ$9 million and 3.5%; NZ$3.5 million and 12.0%, and NZ$2.2 million and 12.9%; an unsatisfactory business outcome suggesting that this scenario is not economically viable (Table 5.3). An improved, but still economically unsatisfactory outcome where NPV becomes positive at 20 and 30 years, is achieved by modelling an increase in sale price from NZ$13-$14 kg^{-1} and an improvement of fish growth rate or time to market size (i.e. from 15 to 12 months). Further but lesser gains can also be obtained through reduced power and feed costs (Table 5.4) or economies of scale by developing a 2,000 tonnes $annum^{-1}$ production business as compared to a 1,000 tonnes $annum^{-1}$ (Table 5.5).

It is important to recognise that the above economic modelling outcomes are entirely dependent on the model and input values used. Intuitively and based on experience with other species, economic viability might be able to be achieved through the use of a less costly RAS and/or production improvements. This may be through the development of more cost-effective feeds and feeding strategies and a selective breeding strategy for faster growth and disease resistance (with selective breeding by the South Australian commercial Yellowtail Kingfish hatchery in its infancy but with potential for gains - Camara and Symonds 2014). In the short term, it is recommended that any focus on intensive RAS for Yellowtail Kingfish in South Australia should be targeted at extending onshore holding of juveniles of this species so that more advanced juveniles can be stocked into sea cages, rather than production based on rearing smaller juvenile fish through to market size. At this time RAS is better used to provide an optimal rearing environment, particularly warmer water temperature, to enhance the growth rates and shorten the time to market above what is achievable at cooler winter and spring ambient temperatures in the sea in the South Australian temperate climate. However, prior to implementation of such a strategy, further R&D is required and would logically occur where the existing South Australian Yellowtail Kingfish hatchery is situated rather than in 2W2W.

Table 5.3: Cash flow projections of a 1,000 tonnes annum^{-1} Yellowtail Kingfish land-based recirculation aquaculture system (RAS) as derived using a model developed by Mussely and Goodwin (2012). Values in New Zealand dollars; cost of production (CoP), capital expenditure (CapEx), operating expenditure (OpExp), net present value (NPV), and internal rate of return (IRR).

Kingfish Cash Flow Model

Tisbe - V2.8

Harvest		**1,000**	tonnes
Growth rate		**15**	months
Biomass		672	tonnes
Sales Yr 10		**$ 13,696,856**	
OpEx year 10		**$ 12,018,137**	per year
CoP		**$ 12.02**	per kg

Investment	**$16,940,431**		
	10 yrs	**25 yrs**	**30 yrs**
IRR	**3.5%**	**12.0%**	**12.9%**
NPV	**-$8,988,202**	**-$ 3,449,036**	**-$ 2,249,201**
Land Area (m²)	**7,091**		

Income	**Yr 1**	**Yr 2**	**Yr 3**	**Yr 4**	**Yr 5**	**Yr 6**	**Yr 7**
Sales	$ -	$ 2,594,888	$ 10,643,024	$ 11,470,902	$ 11,815,029	$ 12,169,480	$ 12,534,564
Investment	$ 11,067,247	$ 5,873,183	$ -	$ -	$ -	$ -	$ -
Loan	$ 962,369	$ 510,712	$ -	$ -	$ -	$ -	$ -
Expenditure							
CapEx							
Land cost	$ 70,909	$ -	$ -	$ -	$ -	$ -	$ -
Buildings	$ 4,067,287	$ 907,250	$ -	$ -	$ -	$ -	$ -
Recirculation Systems	$ 4,058,318	$ 507,290	$ -	$ -	$ -	$ -	$ -
Culture System	$ 141,390	$ 50,272	$ -	$ -	$ -	$ -	$ -
Intake System	$ 1,091,200	$ -	$ -	$ -	$ -	$ -	$ -
Waste Treatment	$ 17,419	$ -	$ -	$ -	$ -	$ -	$ -
Oxygen storage	$ 300,000	$ -	$ -	$ -	$ -	$ -	$ -
Office set up	$ 56,000	$ -	$ -	$ -	$ -	$ -	$ -
Vehicles	$ 122,500	$ -	$ -	$ -	$ -	$ -	$ -
Total	**$ 9,854,115**	**$ 1,464,812**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
Depreciated value	*$ -*	*$ 1,131,893*	*$ 1,131,893*	*$ 1,131,893*	*$ 1,131,893*	*$ 1,131,893*	*$ 1,131,893*
OpEx							
Fingerlings	$ 473,612	$ 975,640	$ 1,004,909	$ 1,035,056	$ 1,066,108	$ 1,098,091	$ 1,131,034
Feed	$ 456,493	$ 3,280,843	$ 4,134,007	$ 4,326,410	$ 4,456,082	$ 4,589,640	$ 4,727,329
Power	$ 473,929	$ 1,836,228	$ 1,960,468	$ 2,019,282	$ 2,079,860	$ 2,142,256	$ 2,206,524
Oxygen/CaOH	$ 6,287	$ 53,263	$ 68,727	$ 72,770	$ 74,953	$ 77,201	$ 79,517
Staff	$ 557,500	$ 836,250	$ 1,115,000	$ 1,148,450	$ 1,182,904	$ 1,218,391	$ 1,254,942
Office	$ 207,682	$ 267,432	$ 439,842	$ 463,527	$ 477,433	$ 491,756	$ 498,978
Maintenance	$ -	$ 54,202	$ 59,622	$ 65,585	$ 72,143	$ 79,357	$ 87,293
Lease costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Processing	$ -	$ 210,112	$ 861,783	$ 928,818	$ 956,682	$ 985,383	$ 1,014,944
Total	**$ 2,175,502**	**$ 7,513,971**	**$ 9,644,359**	**$ 10,059,897**	**$ 10,366,164**	**$ 10,682,075**	**$ 11,000,562**
Finance							
Bank Debt	$ 962,369	$ 1,473,081	$ 1,473,081	$ 1,325,773	$ 1,178,465	$ 1,031,157	$ 883,849
Bank Interest	$ 76,990	$ 117,846	$ 117,846	$ 106,062	$ 94,277	$ 82,493	$ 70,708
Balance	-$ 2,175,502	-$ 4,919,083	$ 998,665	$ 1,411,005	$ 1,448,865	$ 1,487,405	$ 1,534,002
Bank Loan Repayment	$ -	$ -	$ 147,308	$ 147,308	$ 147,308	$ 147,308	$ 147,308
Total Expenditure	$ 12,106,606	$ 9,096,629	$ 9,909,513	$ 10,313,267	$ 10,607,749	$ 10,911,875	$ 11,218,578
Balance	**-$ 12,106,606**	**-$ 18,608,348**	**-$ 17,874,837**	**-$ 16,717,202**	**-$ 15,509,923**	**-$ 14,252,319**	**-$ 12,936,333**

Income	**Yr 8**	**Yr 9**	**Yr 10**	**Yr 20**	**Yr 25**	**Yr 30**		Total
Sales	$ 12,910,601	$ 13,297,919	$ 13,696,856	$ 18,407,430	$ 21,339,256	$ 24,738,046		**$ 480,214,115**
Investment	$ -	$ -	$ -	$ -	$ -	$ -		**$ 16,940,431**
Loan	$ -	$ -	$ -	$ -	$ -	$ -		**$ 1,473,081**
Expenditure								
CapEx								
Land cost	$ -	$ -	$ -	$ -	$ -	$ -		70,909
Buildings	$ -	$ -	$ -	$ -	$ -	$ -		4,974,538
Recirculation Systems	$ -	$ -	$ -	$ -	$ -	$ -		4,565,608
Culture System	$ -	$ -	$ -	$ -	$ -	$ -		191,662
Intake System	$ -	$ -	$ -	$ -	$ -	$ -		1,091,200
Waste Treatment	$ -	$ -	$ -	$ -	$ -	$ -		17,419
Oxygen storage	$ -	$ -	$ -	$ -	$ -	$ -		300,000
Office set up	$ -	$ -	$ -	$ -	$ -	$ -		56,000
Vehicles	$ -	$ -	$ -	$ -	$ -	$ -		122,500
Total	**$ -**	**$ -**	**$ 113,898**	**$ 113,898**	**$ -**	**$ -**		**11,546,724**
Depreciated value	*$ 1,131,893*	*$ 1,131,893*	*$ 1,131,892.72*	*$ 11,389.84*	*$ 11,389.84*	*$ 11,389.84*		11,546,724
OpEx								
Fingerlings	$ 1,164,965	$ 1,199,914	$ 1,235,911	$ 1,660,961.32	$ 1,925,509.40	$ 2,232,193.13		$ 44,590,918
Feed	$ 4,869,149	$ 5,015,223	$ 5,165,680	$ 6,942,241.62	$ 8,047,960.73	$ 9,329,792.23		$ 183,988,717
Power	$ 2,272,720	$ 2,340,901	$ 2,411,128	$ 3,240,354.73	$ 3,756,459.23	$ 4,354,765.79		$ 86,474,852
Oxygen/CaOH	$ 81,903	$ 84,360	$ 86,891	$ 116,773.84	$ 135,372.89	$ 156,934.28		$ 3,090,701
Staff	$ 1,292,591	$ 1,331,368	$ 1,371,309	$ 1,842,925.11	$ 2,136,455.30	$ 2,476,737.24		$ 49,261,729
Office	$ 506,418	$ 514,081	$ 521,973	$ 701,488.14	$ 813,217.02	$ 942,741.40		$ 18,835,500
Maintenance	$ 96,022	$ 105,625	$ 116,187	$ 156,145.74	$ 181,015.70	$ 209,846.81		$ 3,951,687
Lease costs	$ -	$ -	$ -	$ -	$ -	$ -		$ -
Processing	$ 1,045,393	$ 1,076,755	$ 1,109,057	$ 1,490,480.15	$ 1,727,874.99	$ 2,003,080.68		$ 38,883,734
Total	**$ 11,329,159**	**$ 11,668,226**	**$ 12,018,137**	**$ 16,151,371**	**$ 18,723,865**	**$ 21,706,092**		**$ 429,077,838**
Finance								
Bank Debt	$ 736,540	$ 589,232	$ 441,924	-$ 1,031,157	-$ 1,767,697	-$ 2,504,238		
Bank Interest	$ 58,923	$ 47,139	$ 35,354	-$ 82,493	-$ 141,416	-$ 200,339		**-$ 960,059**
Balance	$ 1,581,441	$ 1,629,693	$ 1,678,720	$ 2,256,059	$ 2,615,391	$ 3,031,955		
Bank Loan Repayment	$ 147,308	$ 147,308	$ 147,308	$ 147,308	$ 147,308	$ 147,308		**$ 4,124,627**
Total Expenditure	$ 11,535,391	$ 11,862,673	$ 12,314,697	$ 16,330,085	$ 18,729,758	$ 21,653,061		**$ 109,876,979**
Balance	**-$ 11,561,123**	**-$ 10,125,876**	**-$ 8,743,717**	**$ 9,785,901**	**$ 21,975,649**	**$ 36,424,987**		**$ 36,424,987**

	CoP
Fingerlings	10%
Feed	43%
Power	20%
Oxygen/CaOH	1%
Staff	11%
Office	4%
Maintenance	1%
Lease costs	0%
Processing	9%

Table 5.4: The effect of changes to key production variables on the key economic viability indices of a 1,000 tonnes annum^{-1} Yellowtail Kingfish land-based recirculation aquaculture system (RAS) as derived using a model developed by Mussely and Goodwin (2012). Values in New Zealand dollars; cost of production (CoP), capital expenditure (CapEx), operating expenditure (OpExp), head on gilled and gutted (HOGG), net present value (NPV), internal rate of return (IRR).

	Best estimate	Sale price		Time to harvest		Fingerling price		Feed price		Power price	
		Lower	Higher	Faster	Slower	Lower	Higher	Lower	Higher	Lower	Higher
Sales price HOGG (NZ$)	13	12	14	13	13	13	13	13	13	13	13
Time to harvest (months)	15	15	15	12	18	15	15	15	15	15	15
Fingerling price (NZ$)	3	3	3	3	3	2.5	3.5	3	3	3	3
Feed Price (NZ$)	2500	2500	2500	2500	2500	2500	2500	2000	3000	2500	2500
Power (NZ$)	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.3	0.4
Total CapEx (NZ$) (30 years)	11,546,724	11,546,724	11,546,724	10,351,057	12,957,591	11,546,724	11,546,724	11,546,724	11,546,724	11,546,724	11,546,724
Total OpEx (NZ$) (30 years)	429,077,838	428,388,995	429,766,680	412,767,861	436,406,671	421,646,018	436,509,657	392,280,094	465,875,581	416,724,287	441,431,388
Total Sales (NZ$) (30 years)	480,214,115	443,274,568	517,153,663	482,852,093	477,504,549	480,214,115	480,214,115	480,214,115	480,214,115	480,214,115	480,214,115
Investment (NZ$) (30 years)	-16,940,431	-17,120,281	-16,760,580	-13,911,692	-19,622,869	-16,718,212	-17,162,649	-16,252,761	-17,628,101	-16,636,810	-17,244,051
NPV (NZ$) (10 years)	-8,988,202	-13,204,367	-4,772,038	-4,425,457	-12,181,775	-7,968,574	-10,007,831	-4,328,739	-13,647,666	-7,355,892	-10,620,513
NPV (NZ$) (20 years)	-3,449,036	-9,711,759	2,813,687	1,996,465	-7,145,389	-2,088,129	-4,809,943	2,922,139	-9,820,211	-1,246,042	-5,652,030
NPV (NZ$) (30 years)	-2,249,201	-8,747,476	4,249,074	3,286,805	-6,010,060	-861,570	-3,636,832	4,256,010	-8,754,412	-1,520	-4,496,883
IRR (%) (10 years)	3.5	-2.1	8.6	8.3	0.8	4.6	2.3	9.0	-2.2	5.4	1.5
IRR (%) (20 years)	12.0	8.1	15.6	15.3	10.1	12.8	11.2	15.8	8.3	13.3	10.7
IRR (%) (30 years)	12.9	9.6	16.2	15.9	11.2	13.6	12.2	16.3	9.8	14.0	11.8

Table 5.5: The effect of production capacity (500, 1,000 and 2,000 tonnes annum^{-1}) on the key economic viability indices of a Yellowtail Kingfish land-based recirculation aquaculture system (RAS) as derived using a model developed by Mussely and Goodwin (2012). Values in New Zealand dollars; cost of production (CoP), capital expenditure (CapEx), operating expenditure (OpExp),head on gilled and gutted (HOGG), net present value (NPV), internal rate of return (IRR).

	Best Estimate	System size	
		Lower	Higher
System size (tonnes annum^{-1})	1000	500	2000
System biomass (tonnes)	672	336	1344
CoP (NZ$ kg^{-1})	10.00	10.44	9.23
Sales price HOGG (NZ$)	12	12	12
Time to harvest (months)	15	15	15
Fingerling Price (NZ$)	3	3	3
Feed price (NZ$)	2000	2000	2000
Power (NZ$)	0.21	0.21	0.21
Total CapEx (NZ$) (30 years)	11,546,724	6,321,542	21,144,404
Total Op Ex (NZ$) (30 years)	357,001,311	186,366,056	658,256,559
Total sales (NZ$) (30 years)	443,274,568	221,637,284	886,549,136
Investment (NZ$) (30 years)	-15,582,474	-8,543,607	-27,863,099
NPV (NZ$) (10 years)	-3,974,434	-3,613,222	1,411,008
NPV (NZ$) (20 years)	2,827,799	-628,029	17,753,492
NPV (NZ$) (30 years)	4,051,243	-57,229	20,446,760
IRR (%) (10 years)	9.2	5.9	14.9
IRR (%) (20 years)	15.8	13.3	20.1
IRR (%) (30 years)	16.3	13.9	20.3

5.1.5. Murray Cod Recirculation Aquaculture Systems (RAS)

Rawlinson (2004) provides an economic assessment of Murray Cod aquaculture using AQUAFARMER™, propriety software developed by Fisheries Victoria, with one scenario for a 100 tonnes annum^{-1} intensive RAS, a size now considered too small to achieve effective economies of scale. It is also important to recognise that the RAS modelled is a relatively basic one that would be largely self-assembled on land already owned, and that the best practice industry data used (growth, mortality, equipment and running costs) were limited at the time. As such, the Murray Cod RAS described is very different from the ones costed above for Salmon and Yellowtail Kingfish, the former representing a premium ‘turn-key’ system using the latest components and including extensive pre- and post- start-up training.

Importantly Rawlinson (2004) highlights that lower cost, small-scale entry into the RAS industry is a way to limit financial exposure while gaining valuable experience, but often leads to complex equipment retro-fitting, higher production risk margins and technological short-cuts that may be costly in the medium to long term. Intensive RAS systems involve complex water chemistry in a finely tuned balance, with any deviation from proven designs increasing the farmers risk substantially.

Information in Table 5.6 provides the basic biological, physical and financial assumptions used in the 100 tonnes annum^{-1} Murray Cod RAS economic model and the farm capital, set-up and operating costs as derived from this model (Rawlinson 2004). Capital equipment costs were $1.485 million, and average annual operating costs were $515,000. The highest operating costs were: labour (27%), followed by feed (26%), seedstock (16%), and electricity and fuel (13%).

Table 5.7 summarises the major financial indicators for the same 100 tonnes annum^{-1} Murray Cod RAS (Rawlinson 2004). The 21.6% profit margin (PM) and 13.1% IRR were considered highly favourable for an agribusiness in Victoria at this time indicating a high likelihood of profitability. A sensitivity analysis indicated that harvested product sale price strongly influenced the PM and IRR; these, respectively, being 0.6% and 0% at $11 kg^{-1}, 21.6% and 13.1% at $15 kg^{-1}, and 30% and 23.3% at $19 kg^{-1}.

Since the study by Rawlinson (2004), prices have risen across-the-board, but there have also been considerable improvements in RAS operational efficiency and selective breeding of Murray Cod has led to improvements in growth rate. There also exists the opportunity to offset operating costs to a degree by integration of freshwater Murray Cod RAS with agriculture, whether through use of nutrient enriched wastewater for horticulture or watering crops/pastures, and/or through the use of concentrated organic sludge wastes as fertiliser.

Table 5.6: Assumptions used for an economic model of a 100 tonnes annum^{-1} Murray Cod Recirculation Aquaculture Systems (RAS) and farm capital, set-up and operating costs (A$) based on this model (source: Rawlinson 2004).

	Value
Biological parameters	
Cost of fingerlings ($ fingerling^{-1})	$0.60
Stocking density (kg m^{-3})	100
Food conversion ratio	2.3 to 1.2 over 20 months
Mortality (month 1 and 2)	10%
Growout period	20 months
Sale price kg^{-1} of fish (head on, gilled and gutted)	$15.00
Sale weight of fish (kg)	0.5
Financial parameters	
Discount rate	5%
Corporate tax	36%
Stock insurance (% of turnover)	4%

Farm capital, set-up and operating costs

Equipment	$1,485,000
Capital and operating (Year 0 and 1)	$2,000,000
Seedstock	$168,000
Standing capacity (tonnes)	58
Growout tanks (each 20 m^3)	29
Labour (four full-time staff)	$210,000
Electricity	$114,000
Feed	$305,600
Administration	$15,000
Marketing	$15,000
Fuel	$10,000
Repairs and maintenance	$50,000
Insurance (building and equipment but not stock)	$15,000

Table 5.7: Summary of major financial indicators for a 100 tonnes annum^{-1} Murray Cod Recirculation Aquaculture Systems (RAS) (A$) (source: Rawlinson 2004).

	Value
Cost of operation (Kg^{-1})	$10.14
Sales	$1,603,000
Net present value	$1,253,641
Internal rate of return	13.1%
Profit margin	21.6%
Return of asset	14.7%
Asset turnover	0.7
Cost benefit ratio	1.6
Net profit after tax	$353,000

5.1.6. Mulloway Recirculation Aquaculture Systems (RAS)

To support the SA Riverland based salt interception aquaculture feasibility study by Hutchinson and Flowers (2008), an unpublished economic and sensitivity analysis was undertaken by Econsearch for the Aquaculture Unit, PIRSA (Econsearch, 2008). This work modelled two proposed, but untried, scenarios for farming Mulloway using River Murray salt interception groundwater. The first was a semi-intensive production system with a production capacity of 495 tonnes annum^{-1} and the second was an intensive RAS with a production capacity of 1,640 tonnes annum^{-1}. Only the latter scenario is considered here, both for the production and marketing of plate size (0.8 kg) and larger (3.0 kg) fish.

The base physical parameters for the 1,640 tonnes $annum^{-1}$ RAS are the availability of 16,400 KL of groundwater at 22-24°C and 16-17 ppt, and the use of 410 tanks each with a volume of 40 m^3 (Table 5.8). The base biological production parameters are: Mulloway fry/fingerling costs of $1.12 an individual; feed costs of $1.85 kg^{-1}; stocking rate of 100 kgm^{-3} and over the first 10 years of operation the mortality rate dropping from 17% to 5%; time to market of plate size fish dropping from 17 to 12 months and larger fish from 23-18 months; and FCR dropping from 1:1.7-1:1.2 (Table 5.9). Labour requirements stabilise at 12 permanent and 8 casual staff (Table 5.10) three years after start-up when all infrastructure will have been installed at a capital costs totaling $17,017,000 (Table 5.11). Operating costs vary little after start-up and are $2,629,904 for the first year and $2,915,546 for year 10 (Table 5.12).

The sensitivity analysis undertaken by Econsearch (2008) demonstrates that for the parameters and their ranges assessed, profitability is most affected by changes in product sale price, then the growth rate of the fish, which determines how long they take to reach harvest size. Changes to feed price and the food consumption ratio are of lesser consequence but still important, followed by power and water costs, and lastly, land purchase price, which has least impact because it is an upfront rather than ongoing cost. In the context of pond culture of Mulloway, where fluctuating seasonal ambient water temperatures will be experienced in comparison to the uniform optimum temperatures within RAS, modelling by Econsearch (2008) indicates that a 30% slower time to reach harvest size equates to the 10 year operating profit (before tax) declining from $10 million to $6.7 million, a negative 33% change, and the NPV declining from $15.3 million to -$9.3 million, a negative 161% change.

Table 5.8: Salt-interception Mulloway aquaculture – physical system assumptions for economic and sensitivity analysis (source: Econsearch 2008).

Parameter	Value
Production capacity (tonnes $annum^{-1}$)	1,640
Groundwater temperature (°C)	22-24
Groundwater salinity (ppt)	16-17
Tank volume (m^3)	40
Number of tanks (purchased over 1st 3 years)	410
Estimated water required (KL)	16,400

Table 5.9: Salt-interception Mulloway aquaculture – production assumptions for economic and sensitivity analysis (A$) (source: Econsearch 2008).

	Production of plate size (0.8 kg) fish	Production of larger size (3.0 kg) fish
Stocking density (kg m^{-3})	100	100
Fish weight in each tank (kg $tank^{-1}$)	4,000	4,000
Mortality rate (year 1-2, 2-4, 5-10)	17, 10, 5	17, 10, 5

Number of months from stocking to sale (year 1-2, 2-4, 5-10)	17, 15, 12	23, 20, 18
Average food conversion ratio (year 1-2, 2-4, 5-10)	1.7, 1.3, 1.2	1.7, 1.3, 1.2
Fingerling costs ($ fingerling^{-1})	1.12	1.12
Feed cost ($ kg^{-1})	1.85	1.85
Product (whole fish) sales price ($ kg^{-1} - range; assumed average)	6-18; 10	6-18; 10

Table 5.10 Salt-interception Mulloway aquaculture – labour cost assumptions for economic and sensitivity analysis (source: Econsearch 2008).

Cost	Amount ($ annum^{-1})
Management (from year 1)	
Manager	1 x 50,000
Assistant	1 x 30,000
Hired labour (from year 3 on)	
Permanent	10 x 26,523
Casual	8 x 26,523
Total wages cost	**546,364**

Table 5.11: Salt-interception Mulloway aquaculture – capital expenditure assumptions for economic and sensitivity analysis Information below represents indicative one-off start up costs (A$). On-going costs are not captured below. (source: Econsearch 2008).

	Costs ($)
Plant and equipment	
Water connection	25,000
Production system (year 1)*	8,000,000
Production system (year 2)*	4,400,000
Production system (year 3)*	4,000,000
Air compressor (x2)	10,000
Laboratory equipment	7,000
Workshop equipment	3,000
Freezers	3,000
Motor vehicles	160,000
Furniture, fixtures and fittings	
Office equipment	14,000
Land and buildings	
Storage shed/workshop	15,000

Office/laboratory/amenities/cool room	70,000
Power infrastructure	100,000
Land	200,000
Total capital investment	**17,017,000**

*tank purchases spread over first 3 years

Table 5.12: Salt-interception Mulloway aquaculture – operating cost assumptions for economic and sensitivity analysis Information below represents indicative costs (A$) in both Year 1 and Year 10 of production provided as an example. On-going costs for intervening years are not captured below. (source: Econsearch 2008).

	Costs ($)	
	Year 1	**Year 10**
Accountancy/bank fees	10,000	32,619
Consultants/contractors	80,000	63,339
Communications	4,750	6,198
Depreciation	428,240	847,050
Education/training	2,000	5,219
Electricity	29,250	701,098
Fuel and oils	29,250	204,203
Insurance	8,000	51,976
Interest	1,638,964	142,406
Laboratory supplies and chemicals	2,250	15,708
Lease charges	0	0
Legal expenses	5,000	6,524
Licences & permits	11,250	14,679
Motor vehicle expenses	6,450	23,928
Office expenses	1,200	1,566
Other expenses	250	317
Protective clothing	1,000	1,305
Rates and land taxes	1,000	1,305
Rent	0	0
Repairs & maintenance	18,000	31,315
Travel	2,000	2,610
Wages and on-costs	338,550	745,874
Water supply maintenance	12,500	16,310
Total operating expenses	**2,629,904**	**2,915,546**

5.1.7. Recirculation Aquaculture Systems (RAS) summary

The economic information presented here on intensive RAS varies greatly, partly because of the different engineering complexity of the described systems, the different biological characteristics of the species investigated, and differences in approach to the analyses. This is also because of the paucity of data that comes from operational commercial RAS ventures; most of the information provided is from the modelling of data from small-scale R&D trials, which may or may not reflect the commercial situation. As such, the information presented should only be used as a coarse guide for the capital and operating costs of such a venture, and particularly its economic feasibility.

Patrick Tigges, Billund Aquaculture, 2016 provided a brief and preliminary overview of his views as to the feasibility of RAS aquaculture of a number of species of interest in Australia; these views have been summarized herein. The assessment was based on the species price per kilogram, growth rate, capital RAS cost, operating RAS cost, level of difficulty of farming the species, level of difficulty of handling the species, the company's level of confidence in producing a RAS for farming the species and being able to support the production of the species. The species considered were: Barramundi, Eels, Murray Cod and sturgeon, with Murray Cod the one considered most feasible, followed by Surgeon, Barramundi and Eel. The key advantages of Murray Cod were identified as its good growth rate to market size, high market price and expectation that it will require only a moderately complex RAS and be relatively robust to grow at a dense stocking rate and to handle. The key challenges were identified to be associated with the need to continuously develop and grow markets as production increases, the absence of any operating Murray Cod RAS to validate the estimated production parameters based on R&D and modelling, and the very few people that have hands-on experience with the intensive culture of this species.

While full life-cycle production of Yellowtail Kingfish in RAS is unlikely to be pursued in Australia at present because of the opportunities for expansion of existing sea cage culture ventures in New South Wales, South Australia and Western Australia, the recent development and operation of intensive RAS for the production of this species in Europe suggests potential for the future. Opportunities may exist in the short term to use RAS in Australia to improve the productivity and profitability of the sea cage culture ventures by producing advanced juvenile Yellowtail Kingfish fingerlings prior to stocking them into sea cages.

RAS Barramundi farms exist in Australia, including in South Australia just to the south of 2W2W. The decision to locate additional farms within 2W2W relate to accessing elevated temperature groundwater, but most importantly, whether markets can be grown to accept substantial increases in production volume without the sale price declining. The key to this is determining whether a premium clean and green Australian product can competitively compete with lower priced product produced in Asia as well as product from other locations in Australia farmed in sea cages and land-based ponds in tropical areas and RAS closer to the major markets (Melbourne and Sydney).

RAS farming of Atlantic Salmon in Tasmania is restricted to the smolt stage, with the growout stage of the production cycle undertaken in sea cages. This situation is unlikely to change unless the social license required for in-sea farming becomes more challenging as it has in some western countries overseas, sea temperatures continue to rise due to climate change beyond the acceptable upper tolerance of that required for profitable salmon farming, and/or market demand increases supporting higher sale prices. Atlantic Salmon and Ocean Trout farming in RAS in South Australia is more likely to occur in the south-east of the State than in 2W2W as this is where there is a more readily available and abundant source of cool (<18°C) groundwater as required by these species; Ocean Trout is considered to have the greatest opportunity due to the greater environmental tolerances of this species (Rainbow Trout).

5.2. Pond aquaculture

5.2.1. Mulloway culture

Mulloway is considered to be the finfish species with greatest potential for pond aquaculture in 2W2W, with the relict ponds at Dry Creek Salt Fields (disused salt production ponds) and at Port Broughton (disused prawn aquaculture ponds) the most obvious sites to initiate such development.

Guy and Cowan (2012) undertook a detailed R&D project to assess the feasibility of re-invigorating New South Wales prawn farms through the culture of Mulloway, with pond growout R&D done in association with Palmer Island Mulloway near Yamba, northern New South Wales. Presently this venture is for sale, but for some years it has been the primary land-based commercial Mulloway aquaculture operation in Australia and as such provides an example of what such a development might comprise. Based on various web-based sources, Palmer Island Mulloway maximum production was likely to have been about 100 tonnes annum^{-1} from about 11 ha of 0.09 ha plastic lined earthen ponds, with their 1.8-2.2 kg whole chilled (on ice) mulloway sold at the wholesale markets in Brisbane and Sydney at about \$11.40 kg^{-1}. Eggs and/or fry were sourced from the Port Stephens Fisheries Institute, New South Wales Department of Primary Industries (NSW DPI) hatchery and when these arrived at Palmer Island Mulloway, they were ongrown in tanks until about 10 g in weight prior to being stocked in the ponds, which were bird meshed while the fish were young.

Prior to becoming for sale, Palmer Island Mulloway were assessing moving from the marketing of larger (2 kg) Mulloway preferred by Australian markets to plate size (0.6 kg) Mulloway for which they believed a good, but untested, market existed in Hong Kong at a price of \$14.00 kg^{-1}. The basis for this strategy is believed to be that the fish will take 12 months to reach 0.6 kg, which allows more ponds to be harvested in a 12 month period; fish <700 g have a better FCR than larger fish; and that business risk is reduced by growing fish for one year as compared to two. Speculatively figures provided in Table 5.13 suggest that once sales of 20,000 fish month^{-1} (12,000 kg month^{-1}) are initiated, income and operating cost would be, respectively, \$168,000 and \$100,000 month^{-1} and for the first full year of production (year 3), \$2,016,000 and \$1,202,600 annum^{-1}.

This strategy might provide a reasonable return on investment, although this is ultimately dependent on the development or purchase price of the venture and how this has been incorporated in the business plan.

Much of the developmental research on Mulloway is described in reports on:

- inland saline aquaculture addressing coordination and communication of R&D in Australia (Allan et al. 2008);
- a tank based culture system using saline groundwater in the Riverland of South Australia (Hutchinson and Flowers 2008); and
- evaluating an alternative species for farming in prawn ponds in northern New South Wales (Guy and Cowan 2012).

This R&D provides much useful information for establishing a Mulloway pond aquaculture venture in South Australia, with the derelict ponds at the Dry Creek Salt Fields and past Port Broughton Prawn Farm providing potentially suitable locations. Despite what is known about Mulloway pond aquaculture, detailed on-site evaluations are strongly recommended to address local issues, with these progressing from small scale R&D to pilot scale commercialisation. Key factors that should be examined include:

- management of pond water temperatures through pond depth and flow rates so they do not exceed the critical limits for Mulloway. Guy and Cowan (2012) provide water temperature data from a range of studies highlighting that the optima for Mulloway production are around 20-28°C. Mulloway growth declines below 18°C and they become increasingly stressed below 12°C, with mortalities becoming increasing prevalent between 10°C and 7°C. Above 26°C growth rates and FCR's start to decline with fish accumulating undesirable levels of fat in their flesh when maintained in temperatures above 30°C. The upper critical temperature at which mortality will occur is not known.
- management of pond salinity levels through increased water exchange between the ponds and the sea or less likely the addition of lower salinity water, perhaps from a bore. Salinity should be kept above 5 ppt and below about 40 ppt; the upper critical level leading to mortality is not known.
- management of phytoplankton blooms so as to prevent pH and dissolved oxygen exceeding critical levels and potential harmful algal species developing and causing fish mortalities. pH should be above 6 and for smaller fish below 8.8 and larger fish below 9.6. Dissolved oxygen levels below 1.8 mgL^{-1} result in mortalities. Effective management techniques typically involve reducing water phosphorus levels. This can be achieved by the exchange of water or by the addition of a water treatment product such as 'Phoslock', which is clay based and removes dissolved phosphorus from the water column and forms a protective cap over nutrient enriched sediments.
- minimisation of bird predation, which particularly affects the smaller Mulloway. This is most effectively achieved by meshing ponds or keeping smaller Mulloway in mesh cages within the ponds prior to their release.

- improved feeds and feeding strategies so that they are optimal in relation to varying seasonal pond environmental conditions. Mulloway are typically mid rather than surface feeders so feeding is more challenging to monitor; with excessive feed leading to suboptimal FCR and unnecessary feed costs and undesirable pond water quality issues.
- integrated multi-trophic or polyculture to maximise production, enhance environmental quality and minimise business risk through increased product diversity. Seaweed, polychaete and samphire culture are likely to align well with Mulloway aquaculture in ponds. These species, in particular seaweeds, which have the potential to also be used for the production of higher value-added products, might be useful in compensating for the loss of revenue from Mulloway production over the colder temperature period. This will increase the time to market by about three months as compared to Mulloway undertaken at year-round mid-20s temperatures achievable in RAS.

Table 5.13: Speculative cash flow estimates for pond Mulloway aquaculture for production of plate-size fish (0.6 kg) for export

	Cash flow estimates ($)		
	Year 1	Year 2	Year 3
Income			
Plate size sales export @ $14.00kg	0	1,176,000	2,016,000
TOTAL CASH RECEIPTS	*0*	*1,176,000*	*2,016,000*
Expenditure			
Fish feed - plate size growout	-216,800	-480,000	-480,000
Fish feed - plate size hatchery	-2,400	-1,600	-2,400
Freight out	0	-40,600	-69,600
Freight - export to Hong Kong	0	-84,000	-144,000
Freight in	-7,600	-16,800	-16,800
Electricity	-61,500	-115,500	-115,500
Accounting and IT expenses	-7,200	-7,200	-7,200
Fuel (Petrol & Diesel)	-7,200	-7,200	-7,200
Motor vehicles	-7,200	-8,400	-8,400
Salary and on-costs - manager and 3 casual staff	-111,000	-111,000	-111,000
Rates - council and water	-3,600	-3,600	-3,600
Purchase of assets under $20,000	-4,800	-4,800	-4,800
Office and communications	-3,600	-3,600	-3,600
Maintenance - general	-34,500	-42,000	-42,000
Environmental and processing licences	-2,400	-2,400	-2,400
Processing and packaging	0	-36,000	-54,000
Hatchery supplies including fish eggs	-32,000	-25,000	-25,000
Pond supplies and maintenance	-16,500	-30,000	-30,000
Bank Visa card	-15,000	-18,000	-18,000
Miscellaneous and veterinary	-3,600	-3,600	-3,600
SUBTOTAL	*-546,900*	*-1,078,700*	*-1,202,500*

TOTAL CASH CREDIT OR DEFICIT	**-546,900**	**97,300**	**813,500**

5.2.2. Mulloway aquaculture aligned to ecosystem maintenance and eco-tourism

On the coast adjacent to the southern boundary of 2W2W is the northern extent of the Dry Creek Salt Fields (4,224 ha of ponds) that stretch for 28 km northwards from about 10 km north of Adelaide (BL&A 2015). Until about 2013 this was an operational salt production system with the northern seawater intake at Middle Beach, and a chain of evaporation and then crystallisation ponds stretching south. Water depth was about 1.0-1.5 m in the northern intake pond, but only a few centimetres deep in the southern crystallisation ponds, with water salinity rising as water depth declined due to evaporation (BL&A 2015).

The coastal margin of this salt production system comprises tidal mangroves and saltmarshes that support a high biodiversity, particularly wading seabirds, including internationally significant migratory species (BL&A 2015). It is also an important nursery area for coastal fish species, many of commercial importance (BL&A 2015). With the closure of the privately owned salt production business the South Australian Government has taken on the management of the system, with the intent on reducing water pumping requirements by allowing many ponds to dry but also maintaining biodiversity of the central region by continuing to supply water to this area, which has become part of the Adelaide International Bird Sanctuary.

A very similar ecosystem based around salt fields exists in the Bay of Cadiz in Spain (Yufera and Arias 2010), has included extensive multi-species aquaculture (polyculture) for many years, primarily in the deeper seaward ponds adjacent where water enters the system from the sea. The traditional aquaculture practices consist of a yearly cycle of tidally filling the ponds during late winter and early spring, with the naturally occurring species entering the ponds at this time, then closing off the ponds with nets to retain the desired species. Partial and episodic water exchange is facilitated to maintain pond water quality. The trapped fish species then grow through the period of warmer water temperatures feeding on the natural benthos and small fish, and the ponds harvested at the end of autumn-early winter. The taxa harvested include bream, mullet, flounder/sole, crabs and prawns. Production is noted to have increased over time from about 30 to 300 kg ha^{-1}, with 15-30% of production lost to bird predation.

Yufera and Arias (2010) outline that in response to the decline of the salt production industry in the region, some aquaculturists have expanded the extent and depths of the deeper seaward ponds to continue to undertake extensive polyculture and some have built new ponds for more intensive, semi-intensive monoculture. They indicate, however, that much of the region has been abandoned with ponds drying due to sedimentation, erosion, or because water no longer flow into them, and with this drying there is a loss in biodiversity and as such ecosystem value. The authors describe a case study targeted at addressing this issue by increasing the area of extensive aquaculture, with the objective of enhancing the region’s economic return while maintaining its sustainability and environmental quality. The study is of an existing extensive aquaculture farm of many ponds with a total surface area of 64 ha (c.f. the Dry Creek Salt Fields seaward pond, designated XE 1-3, which has an area of 170 ha), located within a protected area of the Natural Park Bay of Cadiz, and crossed by an eco-tourism path. While the study only marginally increased fish production through improved farm management, they concluded that based on other studies, that more could be achieved, if pond design and water circulation had also been concurrently improved. In conclusion, they advocated the integration of extensive and semi-intensive aquaculture with the natural ecosystem and eco-tourism to enhance the sustainability and profitability of the region.

Incorporation of aquaculture into the northern seawater intake pond area of the Dry Creek Salt Fields has been identified as a possibility by the South Australian Government, based on the assumption that it would involve the development of a semi-intensive pond system (see Section 5.2.1 above), which has been highlighted by a number of local academics and potential investment groups looking at sites for algal production, for which it is suited. Not yet considered, however, is extensive polyculture integrated with ecosystem conservation and eco-tourism, which could potentially increase the pond area utilised thereby increasing the overall flooded area in the region and thus biodiversity. The extensive polyculture practiced could be one or a combination of scenarios:

- as in Spain, where naturally occurring species enter the ponds from the sea, are prevented from leaving and then ongrown with a low level of management until harvested for market by aquaculturists;
- where naturally occurring species enter the pond, are ongrown and people charged an entry or some such other fee, to recreationally fish; and
- stocking the ponds with early life stages of select species from a hatchery (which could be part of the development), where they feed on a natural diet until they grow to a suitable juvenile size for release to the wild (i.e. a stock enhancement program).

Stock enhancement programs are popular overseas as a way to support recreational fishing and in some situations as a management tool to rehabilitate fisheries that have declined. The environment of the Dry Creek Salt Fields and surrounds is well suited for this purpose; hatchery technologies are known for a number of potentially suitable species for restocking, such as Black Bream, King George Whiting, Mulloway and Snapper; and PIRSA Fisheries and Aquaculture have developed appropriate stock enhancement policies and are supporting a number of other stock enhancement activities (e.g. native oyster reef restoration offshore of Ardrossan in Gulf St Vincent, Murray Cod restoration in the River Murray, and native freshwater stocking into select reservoirs). In the USA and interstate, particularly in New South Wales, Queensland and Victoria, there is broad public support for stock enhancement programs aligned with recreational fishing, with community groups also playing a major role in the hatchery and stocking phases. Stock enhancement programs have also been successfully used as an educational tool to promote sustainable fisheries and habitat practices.

5.2.3. Macro- and microalgae

Only two large commercial microalgal production operations exist in Australia, although a number of start-ups are under development. BASF's extensive pond operation near Whyalla, South Australia produces the green algae *Dunaliella salina* (https://csiropedia.csiro.au/beta-carotene-industry-establishment/) and Australian Spirulina's more intensive raceway operation near Darwin, NT produces the blue-green algae *Spirulina* sp. (www.australianspirulina.com.au/). The product from both companies is used primarily as food health supplements for human consumption. In South Australia, prominent research organisations such as SARDI, Flinders University, University of Adelaide and the private company Muradel have undertaken microalgal R&D with a number of clients but to date no commercial start-ups have resulted.

Commercial macroalgal production in Australia lags that of microalgal production, with Venus Shell Systems recently starting intensive land-based tank culture of the green algae *Ulva spp*. in the Shoalhaven region of New South Wales after some years of small-scale research (Winberg et al. 2011). This company is the only known land-based commercial macroalgal culture operation in Australia. A number of companies, however, harvest drift algae from the beaches, including the common southern Australian brown algal kelp *Ecklonia radiata* by Sea Health Products in New South Wales; a variety of species of brown and red algae by Gather Great Ocean Group in South Australia; the brown algal bull kelp *Durvillaea potatorum* by China Kelp Industries on King Island, Tasmania; and the introduced pest brown kelp *Undaria pinnatifida* by Marinova, in Tasmania. These small and localised industries are primarily focused on the production of alginates, bioactives, fertilisers, feeds, food and fucoidens.

While overseas macroalgal (based primarily on in-sea culture in Asia) and land-based microalgal commercial operations have continued to develop and grow to satisfy markets for biomass that can be processed into a range of products, including animal feeds, cosmeceuticals, industrial chemicals, food and food health products, fuels, nutraceuticals and pharmaceuticals, this is not the case in Australia. Although some Australian research has been done in this space, the lack of funding to move from research-scale to pilot commercial-scale operations has hindered commercialisation. While potentially interested investors exist, they are typically concerned about the substantial business risks and costs of starting an operation using an unproven native species requiring to be cultured in an unfamiliar environment in an unproven system.

Economic assessments of micro- and macro-algal culture are relatively limited and those that exist have primarily been developed by researchers and use data based on a wide range of assumptions and scaled to higher production levels than have been tested. The only known economic feasibility study (Froese 2012) developed for South Australia provides a broad review of other such work done globally on micro- and macroalgal production to assess the economic feasibility of a best approximation of what a hypothetical macroalgal raceway/pond production system might comprise and cost to build and operate (Tables 5.14 and 5.15). The feasibility study focused on the concept of growing locally occurring marine green algae of the genera *Ulva* and red algae of the genera *Gracilaria* in the Port Adelaide-St Kilda region north of Adelaide and just to the south of 2W2W. It highlighted that both of these macroalgae have been well researched globally and are cultured commercially in a number of countries for a range of products varying from plant growth promotors, to ingredients in animal feeds and human food; a number of pharmaceutical products are under development. A biorefinery approach (i.e. targeting multiple products and markets) has been advocated as the most likely commercial model to succeed (Froese 2012, Roos et al. 2019).

The culture system advocated by Froese (2012) is based on racetrack-shaped raceways of 40-90 cm deep with a total surface area of 48.5 ha, supplied by either freshwater or seawater depending on the species to be cultivated, and producing a biomass of 3,182 tonnes dry matter annum^{-1} of *Gracilaria* from 44.8 ha and 307 tonnes dry matter annum^{-1} of *Ulva* from 4.6 ha. The key market for the biomass produced was hydrocolloids for *Gracilaria* and abalone feed for *Ulva*.

The feasibility study by Froese (2012) advocates the use of raceways as the preferred culture system for macroalgae, indicating that these can be above or below ground, with the latter more common but requiring greater earth works and excavation. He indicates that the bottom and sides of the ponds can be sealed to prevent water leakage using clay, but more commonly High Density Polyethylene (HDPE) and Geotextile, the latter an EPA requirement in South Australia where pond water contamination of groundwater is considered likely to occur. Froese also advises that the water within the raceways/ponds be circulated, agitated and aerated, either using two strategically located floating paddle wheels or a central bottom mounted aeration pipe. He recommends that carbon be added either through aeration, or more expensively for more intensive culture systems, through carbon dioxide injection from adjacent storage tanks, carbon dioxide generators, or a nearby industrial site (e.g. power station). As nitrogen, phosphorus and other nutrients are required in small amounts to fertilise the growing algae, Froese (2012) proposes that they be sourced either as industrial chemicals or more cost effectively if available, from a nearby wastewater nutrient source.

Froese (2012) highlights that the initial capital cost for a raceway culture system of the type recommended is about $20 million, with the raceways/pond construction being by far the greatest cost. Operating costs were determined to be about $1.7 million annum^{-1}, except in the first year when there was no production because the system was under construction. Salaries for personnel and system maintenance were identified to be far the largest operating costs. Hypothetical annual income based on the production of *Gracilaria* primarily for hydrocolloids (US$1,200 tonnes dry weight^{-1}) and *Ulva* for abalone feed (US$975 tonnes^{-1}) was estimated to be about $4.2 million.

The recently established commercial Venus Shell Systems operation in New South Wales, which cultures *Ulva* in tanks, highlights that there is also the potential to market some if not all the macroalgal biomass produced for use in the production of higher value products such as human food and cosmeceuticals, which is likely to further improve profitability.

Table 5.14: Estimate of the capital costs for a 48.5 ha macroalgal raceway/pond facility (source: Froese 2012).

Category	Cost (US$ in 2011)	Cost per ha (US$ in 2011)
Lined ponds	6,730,000	138,831
Electrical	1,611,355	33,242
Piping	1,407,816	29,044
Carbon dioxide delivery	503,761	10,393
Facility infrastructure	388,421	8,013
Miscellaneous	169,616	3,499
Drying beds	423,606	8,739
Industrial dryer	1,516,602	31,288
Carbon production plant	-	-
Physical construction costs	**12,750,705**	**263,049**
Construction related costs	3,315,183	68,393
Engineering	1,275,071	26,305
Contingency	1,912,606	39,457
Capital expenditure, excluding land	**19,253,565**	**397,205**
Land costs	447,160	9,225
Total capital expenditure	**19,700,725**	**406,430**

Table 5.15: Estimated annual operating costs for 48.5ha macroalgal raceway/pond facility (source: Froese 2012).

Category	Annual operating cost (US$ in 2011)
Personnel	794,000
Nutrients	31,000
Electricity	119,000
Maintenance	578,000
Drying Energy	148,000
Total annual operating cost	**1,669,000**
Depreciation	**876,000**
Loan interest	**1,611,000**

Froese (2012) suggested that cost savings could be achieved by using less expensive land (e.g. ex salt fields) that is well placed in relation to a suitable water supply (e.g. the sea) and may not need to be plastic lined. Further cost savings could be achieved by using water circulating devices to pulse the water during daylight hours only, reducing water exchanges to once per day and utilising wastewater to provide no cost sources of carbon and nutrients. Culturing species or a species mix that maintains high production rates all year round (i.e. avoids a significant decline in winter often due to reduced day length and to a lesser degree light intensity) would also be beneficial. Economy of scale was suggested to occur up to a size of 100 ha but not thereafter (c.f. 500 ha for commercial microalgal production).

The study by Froese (2012) concluded that the proposed large-scale hypothetical macroalgal production model demonstrated economically viability for some of the scenarios evaluated, although it should be noted that this conclusion was based on no-cost carbon and nutrient supplies from a nearby power station and industrial wastewater source. It was also concluded that more research is required to fill the gaps in knowledge and decrease business risk by providing greater accuracy with respect to the assumptions used in the economic model.

The Dry Creek Salt Field and Port Broughton prawn ponds are considered the most suitable sites for either commercial micro- or macro-algal production within 2W2W, either as monospecific 'crops', or in association with finfish farming as a wastewater remediation system. Any such venture should, however, begin with small and then demonstration scale R&D followed by pilot commercial scale R&D prior to commercialisation, so as to address the many uncertainties that exist and reduce business risk.

5.3. Multi-species hatchery

As a result of the predicted continued growth of aquaculture in South Australia, Australia and globally, substantial opportunity exists to supply juveniles of various species to use to stock farms for growout. Opportunities also exist to supply juveniles for stock rehabilitation or enhancing recreational fishing.

The term 'hatchery' is often a misnomer, as hatcheries typically comprise broodstock, hatchery, larval rearing, live feed production and early-stage nursery facilities. While the supply of juvenile stock can come from hatcheries that are part of vertically integrated aquaculture operations, many consider that dedicated hatchery companies provide the best solution as these are more likely to be able to supply cheaper and higher quality juvenile stock. This is because dedicated hatcheries typically target the production of higher volume of juvenile stock and support comprehensive selective breeding programs as part of their operation to continually improve the stock produced. Dedicated hatcheries are also more likely to be managed and operated by staff with specific expertise in the required fields and incorporate the specialised facilities and equipment to operate hatcheries at maximum efficiency.

A well sited hatchery ideally has ready access to a consistent, high quality, supply of marine and freshwater to ensure optimal growth and survival of the cultured species; three phase power to supply electricity (and solar or wind energy to offset costs); road, rail and air transport for feed and product delivery; and infrastructure and services that provide an ideal environment for attracting and retaining their personnel. While hatcheries may have a flow-through water supply, most operate on partial recirculation, with the amount of recirculation varying across the facility. The supply of fresh and marine water is so that the widest possible range of species can be bred and reared, but also because the system and species can be kept disease and pest free without additional and often costly chemicals by treating them with the 'opposite' water supply to that which they are cultured in. Seawater makes an excellent therapeutic for freshwater species, and freshwater, for seawater species.

An important economic consideration is that economies of scale have been found to be critical to achieve profitable hatcheries. A $2-5 million dollar hatchery, with cost highly dependent on the infrastructure required for appropriate water supply and discharge and whether a breeding program is incorporated, with 6-10 staff can almost as readily produce and distribute 5 as compared to 2 million fry/fingerlings annum^{-1}. While the latter production level may be profitable, hatcheries producing 6-15 million fry/fingerlings annum^{-1} will be much more so based on overseas experiences. While fry and eggs are sold, fingerling are the most common product with prices for large quantities ranging from about \$0.02 mm^{-1} in length for native freshwater finfish to \$0.10 mm^{-1} in length for more challenging marine species.

Although all endemic juvenile native freshwater finfish for land-based aquaculture and stock rehabilitation are imported into South Australia with appropriate disease-free certification from interstate hatcheries, there are a number of commercial hatcheries for other species in South Australia, including multiple ones for Abalone and Oysters and a single one for Barramundi (Robarra, West Beach, Adelaide) and another for Yellowtail Kingfish (Clean Seas Seafood, Arno Bay). Robarra's hatchery is unique in that it has ready access to seawater, warm lower salinity groundwater and is close to Adelaide airport, all characteristics ideal for a Barramundi hatchery, but also a hatchery that might seek to address multiple species. Robarra, besides supplying its own growout operation at Robe in South Australia, exports a substantial number of juvenile stock overseas in response to Barramundi farming expanding globally, particularly in Asia (a similar strategy to the large RAS Barramundi farm and hatchery, MainStream Aquaculture, near Melbourne, Victoria). The broader benefit of hatcheries to aquaculture development is demonstrated by the SARDI Aquatic Sciences R&D Hatchery at West Beach, Adelaide, which over the last 25 years has been used many times to provide start-ups with stock (e.g. Native Oysters and Snapper), undertake feasibility studies (e.g. King George Whiting and Mulloway), and on occasion to address industry stock deficiencies due to disease (e.g. Oysters struggling to survive Pacific Oyster Mortality Syndrome). Research hatcheries have undertaken similar roles in other states in Australia, as well as globally.

Potentially suitable sites for hatcheries in 2W2W would align with adjacent stocking areas, whether for aquaculture, stock rehabilitation or recreational fishing; suitable water supplies (fresh and/or marine) and near-by transport, particularly air, for servicing distant intra, interstate and overseas markets. Areas in the southern 2W2W, as well as closer to Adelaide, are likely to be most suitable due to the presence of the T2 aquifer with its elevated water temperatures, Adelaide Airport for transport, and the possibility of an increased need for hatchery produced juvenile stock for aquaculture within the gulfs, as well as the stocking of near-by freshwater reservoirs, rivers, streams and coastal waters for recreational fishing purposes. Hatcheries located in the upper reaches of the gulfs are less likely to be successful due to the more limited supplies of freshwater, and the summer and winter extremes of salinity and temperature that characterise the shallow coastal waters.

5.4. Aquaponics

Aquaponics, the incorporation of aquaculture and horticulture, is logical in 2W2W to enhance the productivity and sustainability of the region and while technologically feasible, has yet to occur for a variety of reasons. To highlight the challenges and development potential a brief overview is presented of a number of recent aquaponics developments internationally as well as in Australia.

5.4.1. International examples

A recent commercial aquaponics development in the USA comprises a partnership between a RAS design and construction company, and a company already involved in hydroponics in in the city of Saint Paul, Minnesota, USA (Pentair 2016). This venture, established in a historic building with space provided for other start-ups, comprises an 8,083 m^2 indoor aquaponics farm, said to be one of the largest in the world, with the capacity to grow 125 tonnes of finfish and 215 tonnes of organic produce annually. The fish and produce are sold at regional supermarkets, co-ops, restaurants and to a group of hospitals and clinics to provide fresh greens for patient meals, cafeteria salad bars and retail take-out locations.

In Europe, the largest aquaponics producer is NerBreen (https://www.imbrsea.ugent.be/taxonomy/term/44791) in Hondarribia, Spain (Milicic et al. 2017). Their operation is about 6,000 m^2 in area and produces about 70 tonnes annum^{-1} of Tilapia and 20 tonnes of tomatoes, strawberries, lettuce and herbs. The crops production has an area of 3,000 m^2 with afish production are of 1,600 m^2, a fish hatchery and nursery area of 200 m^2, and storage of rainwater from the greenhouse roofs of 600 m^2. The remaining 200 m^2 is used for general use, storage, vermiculture and composting.

Another European example, Ecofriendly Farmsystems, was established in 2015 in what was once a brewery in the Schoneberg district of Berlin, Germany, which was turned into a creative hub for artists and start-ups (Grosser 2015). At start-up it raised the equivalent of about $2.1 million with a just-in-time (produces food when needed) food production model the target. Its aquaponics system uses 13 large tanks held at 28-29°C to grow Tilapia to a weight of about 750 g in eight months using filtered rainwater collected from the roof. The operation delivers about 300 boxes of organic herbs and vegetables per week and about 30 tonnes of organic Tilapia per annum to its customers within Berlin.

Urban Farmer, another European aquaponics venture, is based in an ex-factory roof-top facility near the city centre in The Hague, Netherlands. It has a total production area of 1,900 m^2 and produces 19 tonnes annum per annum of fish and 45 tonnes annum per annum of fruit and vegetables (http://urbanfarmers.com/).

Rather than focusing on production, many aquaponics companies become consultants offering services to others. ECF have been establishing turn-key aquaponics systems for clients (http://www.ecf-farmsystems.com/en/), with a number established in Berlin in 2017-2018. The company advocates that they can successfully establish ventures in new sites with or without cost-saving resources present (e.g. waste heat or water sources), in existing greenhouses or RAS, or on industrial wasteland or roofs of existing buildings.

5.4.2. Australian examples

In Australia, like overseas there seems to be many more commercial aquaponics companies marketing expert consulting services and equipment than commercial scale producers, with these companies surviving primarily by suppling equipment, knowledge and training to domestic-scale and hobby aquaponic operators.

Blue Farms and its joint venture partner Urban Ecological Systems Australia (http://www.bluesmartfarms.com/), is located on seven hectares of land owned by the University of Sydney at Cobbitty, western Sydney. This venture started on the ABC Inventors Television Program in 1996; initiated R&D in 2003; developed a 1.2 ha farm in 2012; and as a commercial prototype, established a supply agreement with a major Australian supermarket chain in 2013. Production occurs within a specially constructed glasshouse of 5,000 m^2, which is used to simultaneously grow beds of herbs (e.g. parsley, basil and coriander) and tanks of Barramundi, with product sold each week through its marketing partner to one supermarket chain in New South Wales. The developers on their web site forecast that the system will produce over 10 times more organically-certifiable food than traditional field horticulture and by producing zero effluent is ideally suited to urban and suburban environments. In addition, 90% of the company's income will come from herbs as compared to 10% from Barramundi. The investment cost is said to have been about $7 million, including about $2.5 million of government funds. At the commercial prototype scale, 129,000 herb plants can be produced every 28 days, along with 15-20 tonnes $annum^{-1}$ of Barramundi. It is unsure whether this business continues to operate.

Other Australian examples include:

- Pundi Produce, SA was a commercial aquaponics business located at Monash, SA, which operated from about 2014-2016. It comprised two 3,000 L aquaculture tanks stocked with Murray Cod and eight tables for horticulture products (https://www.youtube.com/watch?v=FZ-ML6Xsk_0), primarily basil, bok choy, coriander, spring onions and strawberries (Brown-Paul 2014). The product produced was supplied through local farmers markets and direct to restaurants.
- Minnamurra Aquaponics, near Kinglake, Victoria operated from about 2005-2008 producing herbs and Murray Cod, which were marketed to local restaurants and other food producing businesses.
- Aquaculture Advantage (https://aquaculture-advantage.com.au/) is an aquaculture and aquaponics business at Lewiston, SA, within 2W2W. It has a very experienced and well-travelled founder and director operating a commercial pilot system on site and providing consultancy services (including establishing commercial, domestic and training systems), and equipment sales and training.

Mr Eugene Moore who undertook a PhD at the University of South Australia investigated the reuse of industrial wastewater for the production of crops, with his focus on reusing wastewater from finfish to grow vegetables in soil and hydroponically. His research site was at Bolivar, just to the south of 2W2W, where he has operated a small experimental Jade Perch production facility to produce the wastewater and run horticulture trials, with support from the South Australian Government's Catalyst Research Grant Scheme with in-kind support from the Salisbury Council. His project demonstrated the potential in the local environment, using native finfish species and common horticulture species that can be readily sold at local markets.

5.4.3. Aquaponics opportunities

Despite commercial-scale aquaponics appearing to be an economically sustainable activity in select locations overseas, and horticulture thriving from the NAP northwards into 2W2W (e.g. P'Petual near Buckland Park, https://www.ppetual.com.au/) and Sundrop near Port Augusta http://www.sundropfarms.com/), no substantial commercial aquaponics ventures have yet developed in this region. This despite a number of suitable native freshwater finfish species such as Barramundi, Jade Perch, Murray Cod and Silver Perch and an experienced consultancy business, Aquaculture Advantage within the southern 2W2W at Lewiston.

Based on this synthesis, the four key challenges to establishing an aquaponics system in South Australia are understood to be:

1. the general lack of knowledge and experience with modern, advanced finfish RAS systems and integrating these with horticulture ventures;
2. an absence of a pilot-commercial scale and commercial scale operations to demonstrate success;
3. the desire of local large-scale advanced horticulturists (e.g. P'Petual and Sundrop) to focus on their core business, as well as their lack of knowledge and experience in finfish farming; and

4. the absence of local finfish RAS companies looking to diversify into horticulture and with the financial investment dollars required to undertake such a venture.

While the commercial challenges are best addressed by industry, increasing awareness and knowledge is something that could be addressed by government. This might include supporting the development and effective networking of the required specialised multi-disciplinary capabilities (biology – aquaculture and horticulture and systems engineering – infrastructure, power and water); the establishment of dedicated R&D; and demonstration facilities that are of a scale that will provide information that is meaningful for commercial up-take. It is suggested that such expertise and facilities might be suitably located at the University of South Australia's Mawson Lakes Campus or the University of Adelaide's Roseworthy Campus, which also hosts SARDI, both north of Adelaide adjacent to the centre of the NAP horticulture industry. Other more novel locations for the establishment of such an aquaponics facility beyond the boundary of 2W2W might be in association with the Urrbrae - Waite Agricultural area (e.g. arboretum, campus, high school, Technical and Further Education (TAFE) and wetlands) or Block 14-The Adelaide Botanic Gardens. These locations have the advantage of being sites where R&D and commercial start-ups occur, and because they are adjacent major research-tertiary education nodes would have access to expertise and involvement of students. They are also close to the centre of the city of Adelaide, which will provide a ready market for fresh, potentially organically certified, produce and where they could be aligned with tourism (c.f. The Eden Project in Cornwall, England - https://www.edenproject.com/).

5.5. Aquaculture feeds

Aquaculture is principally considered in relation to the farming of well-known seafood species for human consumption (e.g. crustaceans finfish and molluscs) and for specialised products (e.g. crocodile leather and pearls). However, aquaculture also leads to the development of many associated industries (e.g. infrastructure construction, aquafeed production, and product processing and transport) and services (e.g. environmental assessment and monitoring, R&D, and veterinarian). These value-add the total economic benefits of aquaculture.

One important area is aquafeed production, with feed often said to comprise 40-55% of the operational costs of an aquaculture venture (e.g. finfish farming). With the global growth of aquaculture and finite supplies of the small pelagic species used to produce fish meal (protein) and fish oil (lipid), prices of these two components continue to rise. This has instigated considerable research into alternative feed ingredients with the focus on the utilisation of previously unused fish wastes, terrestrial stock (various meat and poultry products) and plant sources (e.g. canola and soya bean meal). Seafood is increasingly being consumed because of its perceived health benefits, in particular marine finfish species with high omega-3 oil levels. As such, many alternative sources of fish meal and oil need to be incorporated as a percentage of the total diet and these frequently need to be nutritionally balanced (e.g. the amino acid profile) to provide the nutritional profile desired in the marketed product by the consumer.

As part of this search for alternative fish meals and oils, and also to meet specialised niche markets, the culture of a range of other organisms have begun, including barnacles (Holland 2018), insects and polychaetes. Until recently the emphasis has been on R&D, but a number of overseas companies are now providing product commercially, demonstrating that suitable culture techniques have been established, there are sizable markets and production can be done profitably, with insects and polychaetes in land-based systems.

5.5.1. Polychaete worms

A number of taxa of marine polychaete worms are being aquacultured overseas in pond and RAS. In Australia, tubeworm are only known to be aquacultured on the central coast of New South Wales, Australia by the company Aquabait. It uses RAS for broodstock and hatchery operations and flow-through raceways for growout (https://www.aquabait.com.au/). Aquabait also markets wild harvested bloodworms and sandworms.

In 1999, the European baitfish worm market value was about €200 million and in 1977 the UK, Netherlands and Ireland aquaculture market value for the single species, *Neris virens,* was about €2.9 million (Olive 1999). The Australian market is unknown, but in South Australia about 14 tonnes of wild-caught worms were harvested by five licensed commercial operators in 2000, with levels from 2002-03 to 2007-08 at about 7 tonnes (Davies et al. 2009). South Australian recreational fisheres also collect polychaete worms for personal use as bait, but the amount is unknown.

Globally, three primary higher price markets are targeted by polychaete worm producers:

- bait for recreational and commercial fishing;
- maturation and juvenile diets for crustacean (prawn) and finfish broodstock; and
- feed for aquarium species.

These products are typically marketed alive or preserved, the latter in small frozen packets, freeze-dried in plastic tubs (e.g. Aquabait - 120 g for $29.95-39.95), or incorporated as a component in specialised pelleted aquaculture feeds, primarily those for larvae and broodstock. A survey of South Australian retailers by Davies et al. (2009) indicated that 84% sell preserved worms as compared to 24% live worms. This was largely the result of 85% of retailer seeking their product locally and only 15% from interstate, and that the supply and capacity to hold preserved worms was much more reliable than live (76% to 24%, respectively). From the scientific literature, it is evident that in the longer term, large polychaete worm producers are looking to supply the much larger aquaculture pelleted feed market, but this will be dependent on substantially increasing production and reducing production costs.

Besides the economic driver to produce polychaete worms, there are also a number of environmental ones. Aquaculture rather than wild-capture, will reduce the environmental effect of digging for worms in their natural environment, an activity that can result in disturbance to feeding and nesting shore birds, bring heavy metals and anoxic and high nutrients water to the sediment surface, and cause over-fishing. As polychaete worms are detritivores that consume particulate organic matter, they are also useful in maintaining the environmental quality of sediments (e.g. sand beds in aquaria and seafloor sediments under cage fish farms located in the sea or large ponds or reservoirs) and processing organic wastes from semi-intensive raceway or intensive RAS fish farms (e.g. Brown et al. 2011). The local culture of polychaete worms also minimises the likelihood of pests or pathogen introductions/transfers (e.g. Davies et al. 2009).

The exact culture requirements vary between polychaete worm taxa. A number of species have been shown to be:

- readily bred, reared and harvested;
- grown to market size within 3-12 months;
- have broad environmental tolerances, with optima that can be achieved in many parts of Australia; and
- provided a diet that is easily formulated, fed and is low cost (particularly if derived from organic waste from aquaculture).

Polychaete worms have also been shown to have an ideal fatty acid profile for use as aquaculture maturation diets, particularly for prawns, and have anti-bacterial and anti-fungal properties.

Biosecure production of such feeds is also of importance when used as aquafeeds. Traditionally prawn broodstock were fed fresh polychaete worms along with other fresh organisms, a practice now known to be highly undesirable given that polychaete worms can have and transmit white spot syndrome virus (WSSV). This is a major concern to the prawn aquaculture industry as infected broodstock are likely to transmit the disease to their offspring (Vijayan et al. 2005). Biosecurity can be achieved by either siting the polychaete worm culture facility remote from the species that the product will be fed to, or by treating the product produced, although some such treatments (e.g. high heat) can affect the quality of the product.

Davies et al. (2009) examined the supply and demand for bait-worms (polychaetes) in South Australia and concluded that aquaculture had potential. A semi-intensive growout system is suggested as the most feasible to begin with (c.f. the company Aquabait in New South Wales) at an onshore location adjacent to calm, estuarine, seawater, such as can be found within the southern part of 2W2W at the Dry Creek Salt Fields or at Port Broughton in central 2W2W. Alternatively, integrating polychaete worm culture with a marine RAS venture or semi-intensive pond culture of finfish would be effective in utilising the organic wastes resulting from such activities and as such a worthwhile add-on (c.f. worm farming that has been practiced overseas and interstate using the organic wastes from freshwater trout raceways).

It is recommended that any such venture initially work towards a demonstration-scale R&D project (e.g. the University of Maine has such a facility that produces 2.5 million polychaete worms annually weighing 7 tonnes) to establish the economic viability of such a venture prior to any larger-scale development. Subsequent up-scaling, research to reduce the time to reach market size, and increasing stock densities will all improve profitability. Given South Australia's substantial sea cage based Southern Bluefin Tuna aquaculture sector, and growing Yellowtail Kingfish and Mussel farming sectors, it may also be worth undertaking R&D to establish the feasibility of using polychaete worms to assist bio-remediation of the sediments below these ventures. However, it should be noted that some taxa of polychaete worms can be the intermediate host of internal parasitic blood worms that can cause significant mortalities of such species as tuna and Yellowtail Kingfish and as such, that such interactions should first be assessed. Berstrom et al. (2017) have reported that increased abundance of the polychaete, *Hediste diversicolor,* significantly improved sediment oxygenation, decomposition of organic matter, pore water sulfide levels and the flux of nutrients across the sediment-water interface. However, they considered thatthe improvements to have occurred primarily from the indirect effect of microbial activity due to the burrowing activity of polychaete worms. The Centre for Cooperative Aquaculture Research, The University of Maine, USA is undertaking trials using the polychaete, *Neris virens* beneath Atlantic Salmon sea cages, (chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://umaine.edu/cooperative-aquaculture/wp-content/uploads/sites/75/2016/04/Polychaete-salmon-report1.2.pdf) but the outcomes have yet to be reported.

5.5.2. Insects

Interest has rapidly been increasing in the use of insects for human consumption and in aquafeeds. A wide range of wild-caught insects have been consumed in Asia for centuries, but their consumption in Western countries has been non-existent and even now is a novelty. Globally, a number of companies are now producing Black Soldier Fly (maggot) meal and government approval has recently been given in Europe and the USA for such ingredients to be used in aquafeeds. Production from these few companies is scaling-up and the number of trials being undertaken to demonstrate its suitability as a diet for different aquaculture species is growing.

The attractiveness of farming insects is that it can be done at high density in a controlled environment in intensive systems. The main input, the feed, can be based on waste products from other industries, given the effectiveness of maggots at consuming these wastes and converting them to biomass.

At least one entrepreneur has considered establishing a maggot meal operation in South Australia, primarily for aquafeeds. Potential sites ideally need to be near a ready source of organic waste to use as food for the maggots (e.g. fish, meat (abattoirs) and/or vegetable processing facilities) and outside the boundaries of, but adjacent to, a significant population centre so as to be able to access cheap land but readily obtain a workforce and to have access to the normal infrastructure and services required to operate such a business (i.e. three phase power, transport, etc.). Two locations suggested during this project were Murray Bridge and Port Augusta, the latter within 2W2W. A recent additional attraction at Port Augusta is the establishment of the national Fruit Fly Research Centre, which has facilities, equipment and people that would be useful for the development insect production for aquafeeds.

5.6. Aquaculture aligned to pumped hydro energy systems

Pumped hydro energy systems (PHES) are presently of considerable interest in South Australia and have been proposed adjacent to 2W2W. As they involve water sourcing, storing and circulation by pumping and gravity, as well as the production of electricity and connection to the South Australian electricity grid, synergies might exist in the alignment of aquaculture and aquaponics with such developments.

South Australia leads the nation in the proportion of energy provided by variable renewable electricity sources, specifically wind and solar. As such there has been considerable interest in energy storage systems to smooth the characteristic fluctuations that arise from these sources. Two strategies have been identified: the use of large storage batteries and PHES (Dayman 2017), with the former typically providing energy storage times of 1-2 hours and the latter 10-20 hours. PHES involve pumping water from a source to an elevated storage reservoir, with this water then released when energy production is required to flow downhill through a pipe back to the source reservoir. Turbines within the pipe generate electricity (Dayman 2017). The only additional water required is that to replace evaporation and seepage from the reservoirs. The cyclic process is aligned to the use of available cheap energy to pump the water to the elevated reservoir and to generate energy when it is less available and more expensive. The volume of water stored within the elevated reservoir determines the energy storage capacity of the PHES system.

Freshwater PHES systems are commonplace in Australia, particularly in the wetter and more mountainous areas of Tasmania and New South Wales. However, the concept of using saltwater, as has been suggested for some PHES in South Australia is novel, with only one such system having been developed and operated globally, in Okinawa in Japan.

The 2W2W, from Port Pirie to Port Augusta, is bounded by the southern Flinders Ranges to the east and from Whyalla to Port Augusta by some higher relief area to the west. These higher relief areas are relatively close to the northern Spencer Gulf coast where seawater might be accessed. A recent report (ANU 2017) identified 185 potential PHES sites in South Australia, of which a number are within the Port Pirie to Port Augusta area. A PHES trial is also currently underway within the Cultana Defence Training Area between Whyalla and Port Augusta (Energy Australia 2017), which also has a high-capacity energy transmission line running through it that would enable connection to South Australia's major energy grid. The Australian Renewable Energy Agency, Energy Australia, Arup and the Melbourne Energy Institute are collaborating to evaluate the concept of establishing a 100-250 MW system able to provides 6-8 hours energy storage, with the intent that if it is commercially viable to have a system operational by about 2020-21. Another is being discussed using the Baroota Reservoir, inland from Port Germain.

It appears that PHES may have the potential to provide a unique source of water for aquaculture in areas where natural supplies are limited. Water from PHES might also be well aerated, under pressure (reducing the need for pumping), and have more stable physical and chemical characteristics than some natural waters. However, the operational characteristics of PHES, such as intermittent water release and energy production, the possible use of chemicals to clean pipes, super-saturation of gases due to pump cavitation, and potentially increasing water salinity due to water evaporation may be problematic for aquaculture. A more detailed understanding of proposed PHES in 2W2W is required, but it should be noted that the alignment of marine aquaculture with a seawater PHES would be an international first with potential to replicate a successful system globally, and as such have the potential to attract investors that might not otherwise be interested.

Possible aligned aquaculture might include:

- the stocking of reservoirs or adjacent ponds with hatchery produced fish for put-and-take recreational fishing ventures, which would have increased novelty if stocked with marine species; and
- RAS, including as a component of aquaponics.

6. Conclusion

The feasibility of land-based aquaculture in the 2W2W to create economic and employment opportunities has been investigated through a synthesis of existing knowledge. This synthesis, involved a literature/data review, ground-truthing and communication with many people with relevant specialised knowledge.

This report addresses the nature of past and existing aquaculture ventures, the broad type of aquaculture technologies potentially suitable for use, the aquaculture species of interest and the nature of the water sources and environment in the region. It highlights a number of potential aquaculture opportunities, presenting a number of economic and sensitivity analyses that have been undertaken by others on some of these.

The region is characterised by a dry temperate climate, becoming increasingly arid to the north. Due to low rainfall and high evaporation rates there is little surface freshwater or potential for freshwater pond aquaculture. While the region includes a number of larger country cities and towns, and some coastal areas are becoming increasingly popular tourist destinations, much of it is sparsely populated. A number of the larger population centres and a few areas associated with mining and/or processing have localised pollution issues that affect small areas of soil and groundwater, which may make them unsuitable for aquaculture without additional investigation and/or remediation.

Reticulated water occurs across 2W2W but is not available at all locations, is expensive and can have less than ideal water quality for aquaculture. Surface waters are limited and where they occur are often ephemeral or greatly reduced in times of drought. Subsurface groundwater is available across much of the region and is a potentially important resource for aquaculture. However, its quality, in particular salinity, is variable with bore location and depth, and the quantity available is typically limited due to low aquifer recharge rates and its existing utilisation.

While much of the coastal area of 2W2W is characterised by farming land, there is also considerable area that has high environmental significance with samphires, mangroves, mud flats and seagrasses providing important breeding and feeding habitat for a wide range of birds and fishes. Such area is unlikely to be approved for aquaculture use.

From an assimilation of the relevant information, a number of potential aquaculture business opportunities were identified. The primary opportunities are:

- The use of intensive RAS to farm
    - Barramundi (estuarine) to grow this existing land-based South Australian industry sector;

- Yellowtail Kingfish (marine) to diversify this South Australian industry sector from its present reliance on growout in cages in the sea at ambient temperatures to an onshore system where the environment can be controlled; and
- Murray Cod (freshwater) to develop an almost non-existent industry sector in South Australia for a species with an iconic status for marketing and a declining supply from the wild.

These species are suggested because they have an existing moderate to high market value and acceptance; local, national and international markets exist; and there is a moderate amount of biological and basic aquaculture related information available, although not for intensive RAS, except for Barramundi.

To potentially increase profitability, diversify business risk and enhance environmental stewardship it may be possible for core aquaculture businesses to be supplemented by effective use of the nutrient enriched wastewater from the RAS for other purposes, with fresh wastewater having the greatest potential as it is suitable for horticulture and/or agriculture. The benefits of using such wastewater have been increasingly demonstrated in commercial operations overseas, including in aquaponics.

The key challenges to the development and success of this opportunity have been identified as:

- the potential high cost of such systems;
- the lack of specific biological and economic information relating to the species recommended for farming in such systems;
- the limited hands-on 'world's best practice' knowledge for establishing and operating such systems;
- the local availability of cheap hatchery produced fish for stocking the RAS; and
- the challenge of developing new markets and maintaining a satisfactory market price as the production of a species increases.

- The use of seawater filled ponds to farm Mulloway, a temperate, native, estuarine species that has been well researche; grows rapidly to market size; has a moderate market price and consumer acceptance; and has been commercially farmed in Australia. Two preferred sites for the farming of Mulloway in ponds have been identified, one within 2W2W near Port Broughton and the other just south of 2W2W at Dry Creek. Both sites are adjacent to gulf waters, with existing access to saltwater. They have also both been previously impacted by past activities that utilised ponds (aquaculture and salt production), which should facilitate development approval.

To potentially increase profitability and diversify business risk it has been suggested that the core semi-intensive aquaculture business should be supplemented by offering an enhanced fishing experience for recreational fishers by incorporating ‘put and catch’ ponds. In addition, this may be achieved by incorporating environmental tourism and education aligned with the establishment of an integrated biosystem approach to aquaculture, and promotion and viewing of the natural characteristics of the adjacent samphire, mangrove, mud flat and seagrass ecosystems. If finfish aquaculture is initiated, seaweed culture could potentially be used to assimilate nutrients from the discharge water, with potential existing to develop products and markets for the seaweed produced. Polychaete worm culture might similarly be undertaken, to assimilate organic matter in the sediments, and produce product for the baitfish and aquaculture feed markets.

The key challenges to the development and success of this opportunity have been identified as:

- the negative effects of winter water temperature on Mulloway growth;
- bird predation during the growout of juvenile fish in ponds;
- the absence of locally available hatchery produced fish for stocking the ponds; and
- the largely unknown effect of increased supplies of farmed Mulloway on the markets, including product price.

The lack of site-specific data relevant to such a venture means that any such development should be undertaken cautiously, starting small and slowly expanding.

- A multi-species hatchery, ideally with access to fresh and saline water, and sited close to transport facilities, targeting the provision of early-stage juvenile finfish species. In particular this could include Barramundi and Murray Cod, which have both national and overseas markets, but also potentially such species as Black Bream and Mulloway (estuarine), King George whiting (marine) and Murray Cod and Silver Perch (freshwater) for stock enhancement of land-based and coastal waters to enhance fishing, and for supply to local aquaculturists as the aquaculture industry continues to grow in South Australia and nationally.

A number of more speculative and/or longer-term opportunities have also been highlighted for land-based aquaculture in 2W2W. These include the production of macro- and micro-algae, polychaete worms and insects that can be processed into higher value bio-products such as animal feeds, cosmeceuticals, functional foods and nutraceuticals. Another potential opportunity is to incorporate land-based aquaculture with horticulture, specifically aquaponics. Although this is a growing industry in Europe and the USA, its development in South Australia is considered to be presently inhibited by a number of factors that are only likely to be overcome through directed actions to build the confidence of existing horticulturists to invest in such activities. Pumped hydro-energy, a novel approach to power generation in South Australia and only presently in the planning stage, has also been identified as an area to explore for associated aquaculture opportunities.

Aquaculture has been, and will continue to be, a major growth sector for primary industries in South Australia. The key risks to aquaculture investment relate to the limited information that exists for many species and culture systems, particularly at a commercial scale (i.e. biological, environmental, technological and markets); and environmental events and/or system failures can cause high mortality of farmed animals very rapidly. In addition, while business plans can be found in the literature and on-line for various scenarios, most are based on many assumptions, populated with data from research rather than commercial operations, and are often quite specific to the situation they describe. The production data and proven business plans of established businesses are typically commercially guarded and are rarely available for general use.

7. References

ABARES 2017. http://www.abs.gov.au/websitedbs/censushome.nsf/home/quickstats.

ABARES 2018. Australian Fisheries and Aquaculture Statistics 2017, Canberra, December 2018.

Adell A 2017. Potential of inland freshwater aquaculture in Northern Corridor. Student project, Lund Technical University, Sweden and Land and Water, CSIRO, Adelaide. CSIRO, Australia. 25 pp.

AFMA 2016. Blue-eye trevalla. Australian Fisheries Management Authority, Australian Government. https://www.afma.gov.au/fisheries-management/species/blue-eye-trevalla. Accessed 2016.

AGC 1989. Aquaculture at Port Pirie: A preliminary feasibility study. Report by Australian Groundwater Consultants Pty Ltd for the Port Pirie Development Committee, Port Pirie, South Australia.

AGC 1998. Port Pirie development committee aquaculture at Port Pirie: a preliminary feasibility study. Australian Groundwater Consultants Pty Ltd, Adelaide, South Australia.

Alcoe DW and Berens V 2011. Non-prescribed groundwater resources assessment – Northern Yorke Natural Resources Management Region. Phase 1 – Literature and Data Review. Department for Water, Technical Report 2011/17, Groundwater of South Australia, through Department for Water, Adelaide.

Allan G, Banes B and Fielder S 2011a. Developing commercial inland saline aquaculture in Australia: Part 2 resource inventory and assessment. FRDC Project No. 98/335. NSW Fisheries Final Report Series No. 31. Port Stephens Fisheries Research Institute, New South Wales Fisheries, Nelson Bay, New South Wales.

Allan G, Dignam A and Fielder S 2011b. Developing commercial inland saline aquaculture in Australia: Part 1 R&D plan. FRDC Project No. 98/335. NSW Fisheries Final Report Series No. 30. Port Stephens Fisheries Research Institute, New South Wales Fisheries, Nelson Bay, New South Wales.

Allan GL, Heasman H and Bennison S 2008. Development of industrial-scale inland saline aquaculture: coordination and communication of R&D in Australia. Fisheries Research and Development Corporation (FRDC) project No. 2004/241. New South Wales Department of Fisheries, Port Stephens Fisheries Centre, Nelson Bay, NSW, Australia. 235 pp.

Alvarez-Lajonchere L and Ibarra-Castro L 2013. Aquaculture species selection method applied to marine fish in the Caribbean. Aquaculture 408-409, 20-29.

Anon 1991. A preliminary feasibility study: aquaculture in the District Council of Wakefield Plains. Unpublished report, South Australian Department of Fisheries, Adelaide, South Australia.

Anon 2013. Inland aquaculture in Western Australia: establishing an aquaculture operation – overview and licensing. Fisheries Occasional Publication No. 111, Department of Fisheries Western Australia, Perth, Western Australia. 20 pp.

Anon 2014. Polychaete feeds. HatcheryFeed 2014, p. 21-23. http://www.hatcheryfeed.com/article-files/file_0000540001420565061.pdf.

Anon 2015. Look north. Government of SA and Cities of Playford, Port Adelaide and Enfield, and Salisbury, Adelaide, South Australia. http://looknorth.com.au/.

ANU 2017. Sites for pumped hydro energy storage. Australian National University. http://re100.eng.anu.edu.au/research/phes/.

ANZECC 2000. Australian and New Zealand guidelines for freshwater and marine water quality. Vol 1. The guidelines (Chp 1 – 7). Australian and New Zealand Environment and Conservation Council, Canberra, Australia. https://www.waterquality.gov.au/anz-guidelineshttps://www.environment.gov.au/system/files/resources/53cda9ea-7ec2-49d4-af29-d1dde09e96ef/files/nwqms-guidelines-4-vol1.pdf.

Attorney-General's Department 2017. 30-Year Plan for Greater Adelaide 2010 and 2017 Update. Department of Planning & Local GovernmentAttorney-General's Department, Government of South Australia Adelaide, South Australia. http://livingadelaide.sa.gov.au/. Accessed 2017.

Australian Bureau of Statistics 2016. 2016 Census. https://www.abs.gov.au/websitedbs/censushome.nsf/home/2016, accessed January 2017

Australian Financial Review MagazineEvans S 2017. Alexandra Olsson's gourmet sea salt business Pacific salt is about to expand. The Australian Financial Review Magazine. http://www.afr.com/brand/afr-magazine/alexandra-olssons-gourmet-sea-salt-business-set-to-expand-20170508-gw098t.

Australian Government Department of Defence 2016. Proof & Experimental Establishment, Port Wakefield, South Australia. Department of Defence, Australian Government. http://www.defence.gov.au/id/_Master/docs/NCRP/SA/0665ProofAndExperimentalEstabPortWakefieldSA.pdf.

Badiola M, Mendiola D and Bostock J 2012. Recirculating Aquaculture Systems (RAS) analysis: Main issues on management and future challenges. Aquaculture Engineering, Volume 51, November 2012. p. 26-35.

Baker JL, Shepherd SA, Barrett N and Gurgel CFD AD 2014. Chapter 9. Seagrases of Spencer Gulf. In: Natural History of Spencer Gulf (eds) Shepherd SA, Madigan SM, Gillanders BM, Murray-Jones S and Wiltshire DJ. Royal Society of South Australia, Adelaide, South Australia. p. 137-152.

Barker MF 2015. Chapter 11. Sea urchin aquaculture in New Zealand. In: Echinoderm Aquaculture (eds) Brown N and Eddy S. Wiley – Blackwell. p. 245-262.

Battaglene, SC and Cobcroft, JM 2010. Enhanced hatchery production of striped trumpeter, *Latris lineata*, in Tasmania through system design, microbial control and early weaning. Book 1: Summary. Aquafin CRC Project 1B.4(2), FRDDC Project No. 2004/221. Tasmanian Aquaculture and Fisheries Institute, Hobart, Tasmania. 391 pp.

Benetti DD, O'Hanlon B, Rivera JA, Welch AW, Maxey C and Orhum MR 2010. Growth rates of cobia (*Rachycentron canadum*) cultured in open ocean submerged cages in the Caribbean. Aquaculture 302, 195-201.

Bergstrom P, Carlsson MS, Lindegarth M, Petersen JK, Lindegarth S and Holmer M 2017. Testing the potential for improving quality of sediments impacted by mussel farms using bioturbating polychaete worms. Aquaculture Research 48, 161-176.

Bernatzeder A and Britz PJ 2007. Temperature preference of juvenile dusky kob *Argyrosomus japonicas* (Pisces: Sciaenidae). African Journal of Marine Science 29(3), 539-543.

Bijo PA 2007. Feasibility study of a recirculation aquaculture system. Final Project 2007. The United Nations University, 59pp. https://www.scribd.com/document/213946314/Aquaculture-feasibility-study.

Billund Aquaculture 2016. Quotation Salmon (Salmo salar) 1.000t/Year.

Billund Aquaculture 2017. Quotation Salmon (Salmo salar) 3.000t/Year.

BL&A 2015. Dry Creek Salt Field closure (reports and attachments). Prepared for Ridley Land Corporation Limited. Brett Lane & Associates Pty Ltd, Hawthorn Victoria.

Booth MA 2005. Investigations of the nutritional requirements of Australian snapper *Pagrus auratus* (Bloch & Schneider, 1801). PhD thesis, Queensland University of Technology, Brisbane, Queensland. 193 pp.

Bostock J and Fletcher D 2014. Review of recirculation aquaculture system technologies and their commercial application. Final report prepared for Highlands and Island Enterprise. Stirling Aquaculture, University of Stirling in association with RAS Aquaculture Research Ltd, Stirling, Scotland.

Bowyer JN, Qin JG, Adams LR, and Stone DAJ 2012. The response of digestive enzyme activities and gut histology in yellowtail kingfish (*Seriola lalandi*) to dietary fish oil substitution at different temperatures. Aquaculture 368, 19-28.

Boyd 1979. Water Quality in warmwater fishponds. Auburn University, Alabama, USA, 356pp.

Boyd CE 1990. Water quality in ponds for aquaculture. Auburn University, Alabama, USA.

Bregnballe J 2015. A guide to recirculation aquaculture: an introduction to the new environmentally friendly and highly productive closed fish farming systems. Food and Agricultural Organisation of the United Nations and EUROFISH International Organisation, Rone, Italy.

Bronzi P, Rosenthal H and Gessner J 2011. Global sturgeon aquaculture production: an overview. Journal of Applied Ichthyology 27, 169-175.

Brown N, Eddy S and Plaud S 2011. Utilisation of waste from a marine recirculating fish culture system as a feed source for the polychaete worm, *Nereis virens*. Aquaculture 323-323, 177-183.

Brown-Paul C 2014. Aquaponics in South Australia. Practical Hydroponics and Greenhouses 145, 22-29.

Bryars and Geddes 2005. Effects of diet on the growth, survival and condition of sea-cages adult southern rock lobster, *Jasus edwardsii*. New Zealand Journal of Marine and Freshwater Research, 39(2), 251-262.

Bryars S, Wear R and Collings G 2008. Chapter 11. Seagrasses of Gulf St Vincent and Investigator Strait. In: Natural History of Gulf St Vincent (eds) Shepherd SA, Bryars S, Kirkegaard I, Harbison P and Jennings JT. Royal Society of South Australia, Adelaide, South Australia. p. 106-147.

Bubner E 2011. Towards the captive breeding of the southern bluefin tuna (*Thunnus maccoyii*). PhD Thesis, Flinders University, Adelaide, South Australia. 184 pp.

Bureau of Meteorology 2017. http://www.bom.gov.au/climate/data/?ref=ftr

Bye JAT and Kampf J 2008. Chapter 5. Physical Oceanography. In: Natural History of Gulf St Vincent (eds) Shepherd SA, Bryars S, Kirkegaard I, Harbison P and Jennings JT. Royal Society of South Australia, Adelaide, South Australia. p. 56-70.

Camara MD and Symonds JE 2014. Genetic improvement of New Zealand aquaculture species: programmes, progress and prospects. New Zealand Journal of Marine and Freshwater Research 48, 466-491. DOI: 10.1080/00288330.2014.932291

Chebanov and Galich 2013. Environmental and genetical technological problems of sustainable development of sturgeon culture in Russia. In Science and Society – at the Crossroads. International Symposium on sturgeon. Canada, Nanaimo – 2013. Aquaculture Book, 266p.

Chen B 2014. Addressing causes of early mortality in hatchery produced southern bluefin tuna larvae. Part A: SBT larvae. Australian Seafood CRC Project No. 2011/740. Clean Seas, Port Lincoln, South Australia. 92 pp.

Cleary J and Jenkins GI 2003. Further development of aquaculture techniques for the production of WA Dhufish (*Glaucosoma hebraicum*). Final Report for the Fisheries Research and Development Corporation, FRDC Project No. 1999/322. Aquaculture Development Unit, WA Maritime Training Centre, Challenger TAFE, Fremantle, Western Australia.

Cobcroft J 2012. Improving hatchery production of Yellowtail Kingfish larvae and fingerlings. Australian Seafood CRC Project No. 2010/753. Australian Seafood CRC, Adelaide, South Australia. 91 pp.

Coerco Agriculture 2017. Check out this Sea Monkey Farm in 32,000Ltr Tanks on Google Maps!. https://agriculture.coerco.com.au/agriculture-blog/check-out-this-sea-monkey-farm-in-32000ltr-tanks-on-google-maps. Accessed 2017.

Davies S, Mair G and Harris J 2009. Baitfish survey report 2008 with a focus on the supply and demand for bait-worms in South Australia. School of Biological Sciences, Flinders

University, Adelaide, South Australia. https://www.researchgate.net/publication/228414872_Baitshop_Survey_Report_2008_With_a_focus_on_the_supply_and_demand_for_bait-worms_in_South_Australia.

Dayman I ABC 2017. Explained: pumped hydro and its potential role in South Australia. Australian Broadcasting Corporation. http://www.abc.net.au/news/2017-02-03/pumped-hydro-and-its-potential-in-sa-explained/8233342. Accessed 2017.

de Dezsery A 2010. Commercial integrated farming of aquaculture and horticulture. Fellowship report supported by the Department of Education, Employment and Workplace Relations, Australian Government. International Specialised Skills Institute, Melbourne, Melbourne, Australia. pp. 54.

DEH 2005. Assessment of the South Australian sea urchin fishery. Department of the Environment and Heritage, Australian Government Canberra, Australia. 18 pp.

Department for Infrastructure and Transport. Mid North and Yorke Peninsula, Department for Infrastructure and Planning. https://www.dit.sa.gov.au/__data/assets/pdf_file/0015/5181/5_MID_NORTH_and_YORKE_PENINSULA_38-47.pdf

Department of Fisheries 2013. Inland Aquaculture in Western Australia. Department of Fisheries, Government of Western Australia. http://www.fish.wa.gov.au/Documents/occasional_publications/fop111.pdf. Accessed 2017.

DEWNR 2013. Non-prescribed surface water resources assessment – Northern and Yorke Natural Resource Management Region, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide.

DEWNR 2014. Baroota PWRA surface water status report 2010-11, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide.

DEWNR 2017a. Northern Adelaide Plains PWA T1 aquifer - 2016 Groundwater level and salinity status report, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide.

DEWNR 2017b. Northern Adelaide Plains PWA T2 aquifer - 2016 Groundwater level and salinity status report, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide.

Dittmann S and Baggalley S 2014. Chapter 8. Mangroves and mudflats in Spencer Gulf. In: Natural History of Spencer Gulf (eds) Shepherd SA, Madigan SM, Gillanders BM, Murray-Jones S and Wiltshire DJ. Royal Society of South Australia, Adelaide, South Australia. p. 107-120.

DNB 2017. Seafood – special report: deep dive into land-based farming, 1 February 2017. DNB Markets, a division of DNB Bank ASA, Oslo, Norway. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/http://dyneaquaculture.com/wp-content/uploads/2017/05/DNB-Markets-Deep-dive-into-land-based-farming.pdfhttp://www.kuterra.com/files/1314/9669/9783/DNB_-_Deep_dive_into_land-based_farming.pdf

Doroudi MS, Fielder DS, Allan GL and Webster GK 2006. Combined effects of salinity and potassium concentration on juvenile mulloway (*Argyrosomus japonicas*, Temminck and Schlegel) in inland saline groundwater. Aquaculture Research 37, 1034-1039.

Doupe RG, Sarre GA, Partridge GJ, Lymbery AJ and Jenkins GI 2005. What are the prospects for black bream *Acanthopagrus butcheri* (Munro) aquaculture in salt-affected inland Australia? Aquaculture Research, 36 (14), 1345-1355.

DPIF QLD 2005. Site identification for aquaculture: assessment of chemical contamination in site selection. Department of Primary Industries and Fisheries, Queensland Government, Brisbane, Queensland. https://nla.gov.au/nla.obj-2742725722/view.

Dudley DH 2017. Aquaponic design plans: everything you need to know from backyard to profitable business. Howard Publishing, USA.

Econsearch 2008. Economic and sensitivity analysis for the use of salt interception schemes for aquaculture development. An unpublished report for PIRSA Aquaculture. 72 pp.

Econsearch 2016. The Economic Impact of Aquaculture on the South Australian State and Regional Economies, 2014/15. A report to PIRSA Fisheries and Aquaculture. https://www.pir.sa.gov.au/aquaculture/publications

EconSearch 2018. The economic contribution of aquaculture in the South Australian State and regional economies, 2016/17. A report prepared for PIRSA Fisheries and Aquaculture. http://pir.sa.gov.au/aquaculture/publications

Edyvane, KS 2008. Chapter 19. Macroalgal Biogeography and assemblages of Gulf St Vincent. In: Natural History of Gulf St Vincent (eds) Shepherd SA, Bryars S, Kirkegaard I, Harbison P and Jennings JT. Royal Society of South Australia, Adelaide, South Australia. p. 248-263.

Ellis D, Clarke S, Jeffriess B, van Barneveld R, Nowak B, Thomas P, Ferandes M, Loo M and Padula D 2009. Longer term holding of southern bluefin tuna *Thunnus maccoyii*. Aquafin CRC Project 1A.11, Fisheries Research and Development Corporation Project No. 2004/205. Australian Southern Bluefin Tuna Industry Association, Port Lincoln, South Australia. 189 pp.

Energy Australia 2017. Fact sheet: Cultana pumped hydro project. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.energyaustralia.com.au/sites/default/files/2017-08/Cultana%20Pumped%20Hydro%20Project%20Fact%20Sheet%20-%20August%202017.pdf https://www.energyaustralia.com.au/sites/default/files/201708/Cultana%20Pumped%20Hydro%20Project%20Fact%20Sheet%20-%20August%202017.pdf. Accessed 2017.

Enviro Data SA 2018. Welcome to NatureMaps 2017. https://data.environment.sa.gov.au/NatureMaps/Pages/default.aspx. Accessed 2017.

EPA South Australia 2017. Legislation. https://www.epa.sa.gov.au/about_us/legislation. Accessed 2017.

FAO 2018a. The state of world fisheries and aquaculture 2018: meeting ther sustainable development goals. Food and Agricultural Organisation of the United Nations, Rome, Italy.

FAO 2018b. Statistics-introduction, Fisheries and Aquaculture Department, Food and Agricultural Organisation of the United Nations, Rome, Italy.

Fielder S and Heasman MP 2011. Hatchery manual for the production of Australian Bass, Mulloway and Yellowtail Kingfish. Report for the Aquafin CRC and Fisheries Research and Development Corporation. Industry and Investment, New South Wales Government, Orange, New South Wales.

Fielder SD, Bardsley WJ and Allan GL 2001. Survival and growth of Australian snapper, *Pagrus auratus*, in saline groundwater from inland New South Wales, Australia. Aquaculture 201, 73-90.

Fitzpatrick RW, Thomas BP, and Merry RH 2008. Chapter 9. Acid sulphate soils in Gulf St Vincent. In: Natural History of Gulf St Vincent (eds) Shepherd SA, Bryars S, Kirkegaard I, Harbison P and Jennings JT. Royal Society of South Australia, Adelaide, South Australia. p. 106-120.

Fotedar R, Phillips B, Robertson R, Vidovich S and Harris S 2015. Marron aquaculture in Western Australia. A manual for growers. Marron Growers Association of Western Australia, Majimup, Western Australia. 144 pp.

Fotheringham D and Coleman P 2008. Chapter 7. Salt Marshes. In: Natural History of Gulf St Vincent (eds) Shepherd SA, Bryars S, Kirkegaard I, Harbison P and Jennings JT. Royal Society of South Australia, Adelaide, South Australia. p. 81-94.

Froese F 2012. An economic model for large scale macroalgal production in South Australia. Masters Thesis, Faculty of Forest and Environmental Science, University of Freiburg, Germany in cooperation with

ZEE – Centre for Renewable Energy and SARDI – South Australian Research and Development Institute. University of Freiburg, Germany. 65 pp.

Gaylard S 2014. Chapter 27. Marine pollution within Spencer Gulf. In: Natural History of Spencer Gulf (eds) Shepherd SA, Madigan SM, Gillanders BM, Murray-Jones S and Wiltshire DJ. Royal Society of South Australia, Adelaide, South Australia. p. 378-379.

Gooley GJ and Gavine FM 2003. Integrated agri-aquaculture systems. A resource handbook for Australian industry development. RIRDC Publication No. 03/012, Rural Industry Research and Development Corporation, Canberra, Australian Capital Territory.

Government of Western Australia 2010. Minister opens 'world first' aquaculture project at Port Gregory. https://www.mediastatements.wa.gov.au/Pages/Barnett/2010/04/Minister-opens-%E2%80%98world-first%E2%80%99-aquaculture-project-at-Port-Gregory.aspx. Accessed 2016.

Goyder Institute 2016a. Northern Adelaide Plains Water Stocktake Technical Report, The Goyder Institute for Water Research, Adelaide, South Australia.

Goyder Institute 2016b. Northern Reservoir Pre-feasibility study – surface water resources, The Goyder Institute for Water Research, Adelaide, South Australia.

Grosser M 2015. Sustainability feeding cities with aquaponics. DW. https://www.dw.com/en/sustainably-feeding-cities-with-aquaponics/a-18324980. Accessed 2016.

Grove-Jones R 1986. Experimental cultivation of native (*Ostrea angasi*) and Pacific (*Crassostrea gigas*) oysters in South Australia. South Australian Department of Fisheries, Adelaide, South Australia.

Guy J and Cowan K 2012. Re-invigorating NSW prawn farms through the culture of mulloway. Rural Industry Research and Development Corporation (RIRDC) Project No. PRJ-002273, RIRDC Publication No. 11/178, Canberra, Australian Capital Territory.136 pp.

Ham JM and Hutchinson WG 2003. Spawning and larval rearing research on King George whiting (*Sillaginoides punctatae*) relevant to aquaculture and fisheries biology. Fisheries Research and Development Corporation (FRDC) Final Report, FRDC Project No. 97/314. SARDI Publication No. RD03/0067, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, South Australia.

Harbison P 2008. Chapter 8. Mangroves in Gulf St Vincent. In: Natural History of Gulf St Vincent (eds) Shepherd SA, Bryars S, Kirkegaard I, Harbison P and Jennings JT. Royal Society of South Australia, Adelaide, South Australia. p. 95-105.

Hathurusingha PI 2011. Predictive modelling and experimental studies on taste-taint as geosmin (GSM) and 2-methylisoborneol (MIB) in farmed barramundi (*Lates calcarifer*). PhD Thesis, School of Chemical Engineering, University of Adelaide, Adelaide, South Australia. 253 pp.

Hathurusingha PI and Davey KR 2014. A predictive model for taste taint accumulation in recirculating aquaculture systems (RAS) farmed-fish – demonstrated with geosmin (GSM) and 2-methylisoborneol (MIB). Ecological Modelling 291, 242-249.

Heath P, Stenton J and Jeffs A 2015. Chapter 16. Sea cucumber aquaculture in New Zealand. In: Echinoderm Aquaculture (eds) Brown N and Eddy S. Wiley – Blackwell. p. 353-384.

Heinsbroek L and Karnstra A 1990. Design and performance of water recirculation systems for eel culture. Aquacultural Engineering 9(3), 187-207.

Holland J 2018. Planktonic's cryopreserved nauplii free of vibrio and other bacterial parasites. Global Seafood Alliance. https://www.globalseafood.org/advocate/barnacles-shake-up-live-feeds-aquaculture/. Accessed 2018.

Hone P 1993. Introduction of *Crassostrea gigas* (Pacific oyster) in South Australia. Department of Primary Industries, Fisheries Division, Shellfish Environmental Monitoring Program. Internal Report, South Australian Research and Development Institute (SARDI), Adelaide, South Australia.

Hone P, Madigan SM and Fleming AE 1997. Abalone hatchery manual for Australia. South Australian Research and Development Institute (SARDI), Adelaide, South Australia.

Hortle ME 1981. Sea water culture of rainbow trout. Technical Report 2. Tasmanian Department of Sea Fisheries. 46 pp.

Hough JK 2008. Salt production in South Australia. NESA Journal 50, 32-34.

Hutchinson W and Vandepeer M 2005. Water quality: effects and management on abalone farms. Final Report for the Fisheries Research and Development Corporation, Project No. 2002/200. South Australian Research and Development Institute (Aquatic Sciences), Publication No. RD02/0035-3, Adelaide, South Australia.

Hutchinson W, Jeffrey M, O'Sullivan D, Casement D and Clarke S 2004. Recirculating aquaculture systems: maximizing standards for design, construction and management. Report prepared for the Inland Aquaculture Association of South Australia. Primary Industries and Resources South Australia, Adelaide, South Australia.

Hutchinson W, Mawer S and Clarke S 1997. Development of snapper (*Pagrus auratus*) aquaculture in the upper Spencer Gulf region of South Australia. Part A: Research report. Final Project Report, South Australian Research and development Institute, Adelaide, South Australia.

Hutchinson WG and Flowers T 2008. Research to foster investor attraction and establishment of commercial Aquaculture Parks aligned to major saline groundwater interception schemes in South Australia. Centre for natural Resource Management (CNRM), Project 043713. SARDI Publication No. F2008/001027-1, SARDI Research Report Series No. 317. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 204 pp.

Hutchinson, W and Skordas P 2014. Performance of western king prawn (*Melicertus latisculatus*) in saline groundwater from Bore 24 of the Woolpunds Salt Interception Scheme. Client only report prepared for A-Culture Pty Ltd. South Australian Research and Development Institute (Aquatic Sciences). SARDI Publication No F2014/000199-1. SARDI Research Report Series No. 760. Adelaide, South Australia.

Ingram BA and De Silva SS (eds) 2004. Development of intensive commercial aquaculture production technology for Murray Cod. Final Report to the Fisheries Research and Development Corporation (Project No 199/328). Primary Industries Research Victoria, Department of Primary Industries, Alexandra, Victoria. 202 pp.

Irving AD 2014. Chapter 9. Seagrases of Spencer Gulf. In: Natural History of Spencer Gulf (eds) Shepherd SA, Madigan SM, Gillanders BM, Murray-Jones S and Wiltshire DJ. Royal Society of South Australia, Adelaide, South Australia. p. 121-135.

James P 2007. Lobsters do well in sea-cages: spiny lobster on-growing in New Zealand. Bulletin Fisheries Research Agency, 20, 69-71.

James P, Evensen T and Samuelsen A 2017. Commercial scale sea urchin row enhancement in Norway: enhancement, transport and market assessment. Nofima Report 7/2017., Tromso, Norway. 24 pp.

Jeffs A and Hooker S 2007. Economic feasibility of aquaculture of spiny lobster *Jasus edwardsii* in temperate waters. Journal of the World Aquaculture Society. http://doi.org/10.1111/j.1749-7345.2000.tb00695.x

Jenkins GI, Frankish KR and Partridge GJ 1999. Manual for the hatchery production of black bream (*Acanthopagrus butcheri*). Aquacultue Development Unit, Information Series 1999/1. Fremantle Maritime Centre. 125 pp.

Jones B, Fuller S and Carton AG 2013. Earthy-muddy tainting of cultured barramundi linked to geosmin in tropical northern Australia. Aquaculture Environment Interactions 3, 117-124.

Kampf J 2014. Chapter 4. System models for Spencer Gulf. In: Natural History of Spencer Gulf (eds) Shepherd SA, Madigan SM, Gillanders BM, Murray-Jones S and Wiltshire DJ. Royal Society of South Australia, Adelaide, South Australia. p. 44-68.

Kolkouski S, King J, Watts N, Natale M, Mori A, Cammilleri R and Cammilleri C 2015a. Development of octopus aquaculture. Final Report. FRDC Report No. 2009/206. Fisheries Research Report 262, Department of Fisheries, Western Australia.

Kolkouski S, King J, Watts N, Natale M, Mori A, Cammilleri R and Cammilleri C 2015b. Development of octopus aquaculture. Rearing, handling and system design for Octopus tetricus commercial aquaculture. FRDC Report No. 2009/206. Fisheries Research Report 263, Department of Fisheries, Western Australia.

Kruzic N, Mustac B, Zupan I and Colak S 2016. Meagre (*Argyrosomus regius* Asso, 1801) aquaculture in Croatia. Croatian Journal of Fisheries, 14-19.

Kumar (ed.) 2000. Proceedings of the National Workshop on Wastewater Treatment and Integrated Aquaculture, South Australian Aquatic Sciences Centre, South Australian Research and Development Institute, West Beach South Australia, 17th-18th September 1999. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, South Australia.

Lavens, P and Sorgeloos, P (eds) 1996. FAO Manual for the Culture of Brine Shrimp Artemia in Aquaculture. FAO Fisheries Technical Paper 361, Rome, Italy. 295 pp.

Lawrence 2007. Improved performance of marron using genetics and pond management strategies. Final FRDC Report, Project No. 2000/215. Fisheries Research Contract Report No. 17, Department of Fisheries, Government of Western Australia, North Beach, Western Australia.

Le Francois NR, Lemieux H and Blier PU 2002. Biological and technical evaluation of the potential of marine and the anadromous fish species for cold-water mariculture. Aquaculture Research 33, 95-108.

Lee P, Dutney L, Elizur A, Poole S, Forrest A, Moloney J and Mitris M 2015. The development of an Australian cobia aquaculture industry. Project No. 2011/724, Australia Seafood Cooperative Research Centre, Fisheries Research and Development Corporation and Department of Agriculture and Fisheries, Adelaide, South Australia.

Lennard WA 2005. Aquaponics integration of Murray Cod (*Maccullochella peelii peelii*) aquaculture and lettuce (*Lactuca sativa*) hydroponics. Royal Melbourne Institute of Technology, Melbourne, Victoria. 726 pp.

Loo MGK and Drabsch SL 2008. Chapter 16. Subtidal soft bottom sediments of Gulf St Vincent. In: Natural History of Gulf St Vincent (eds) Shepherd SA, Bryars S, Kirkegaard I, Harbison P and Jennings JT. Royal Society of South Australia, Adelaide, South Australia. p. 95-105.

Love DC, Fry JP, Li X, Hill ES, Genello L, Semmens K and Thompson RE 2015a. Commercial aquaponics production and profitability: findings from an international survey. Aquaculture 435, 67-74.

Love DC, Uhl MS and Genello L 2015b. Energy and water use of s small-scale raft aquaponics system in Baltimore, Maryland, United States. Aquacultural Engineering 68, 19-27.

MainStream Aquaculture 2017. The future of aquaculture is here. https://www.mainstreamaquaculture.com/home/. Accessed 2017.

Maslyuk I and Didenko A 2013. Environmental Assessment Report. Import of Russian, Siberian, Beluga and hybrid between Russian sturgeon and Siberian sturgeon to Australia. Supporting information for application to amend the list of specimens suitable for live import into Australia. Kyiv, Ukraine. https://cupdf.com/document/draft-environment-assessment-report-import-of-russian-siberian-the-domestic-market.html?page=1http://www.environment.gov.au/consultation/sturgeon

McCormack R 2017a. Eel Tailed Catfish (*Tandanus tandanus*). NSW Aquaculture Association Inc. https://nswaqua.com.au/fish-species/eel-tailed-catfish-tandanus-tandanus/. Accessed 2017.

McCormack R 2017b. Golden Perch (*Macquaria ambigua*). NSW Aquaculture Association Inc. http://nswaqua.com.au/fish-species/golden-perch-macquaria-ambigua/. Accessed 2017.

Milicic V, Thorarinsdottir R, Santos MD and Turnsek Hancic M 2017. Commercial aquaponics approaching the European market: to consumers' perceptions of aquaponics products in Europe. Water 9, 80.

Miller DJ, Wright ARM and Fairweather PG 2014. Chapter 6. Benthic habitat mapping in Spencer Gulf. In: Natural History of Spencer Gulf (eds) Shepherd SA, Madigan SM, Gillanders BM, Murray-Jones S and Wiltshire DJ. Royal Society of South Australia, Adelaide, South Australia. p. 80-91.

Modsby D, Koduah A 2017. Australian fisheries and aquaculture statistics 2016, Fisheries Research and Development Corporation project 2017-095. ABARES, Canberra, December. CC BY 4.0.

Molony B 2001. Environmental requirements and tolerances of Rainbow trout (*Oncorhynchus mykiss*) and Brown trout (*Salmo trutta*) with special reference to Western Australia: A review. Fisheries Research Report No. 130, Department of Fisheries, Government of Western Australia, Perth, Western Australia. 27 pp.

Mussely H and Goodwin E 2012. Feasibility of land-based aquaculture in New Zealand. Cawthron Report No. 2094. Cawthron Institute, Nelson, New Zealand.

National Parks and Wildlife Service South Australia 2017. Maps and coordinates. https://www.marineparks.sa.gov.au/maps-and-coordinates. Accessed 2017.

Nayar S, Bott, K and Clarke S 2015. Development of a marine macroalgae industry in South Australia. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2015/000418-1. SARDI Research Report Series No. 873. SARDI. Adelaide, Australia.

Neomar 2014. Landbased Mariculture. https://www.neomar.de/fileadmin/user_upload/Download/neomar_Landbased_Mariculture.pdf.

Norriss JV, Tregonning JE, Lenanton RCJ and Sarre GA 2002. Biological synopsis of the black bream, *Acanthopagrus butcheri* (Munro) (Teleostei: Sparidae) in Western Australia with reference to information from other southern states. Fisheries Research Report No. 93, Department of Fisheries Western Australia, Perth, Western Australia. 44 pp.

NSW Department of Primary Industries 2016a. Barramundi – aquaculture prospects. https://www.dpi.nsw.gov.au/fishing/aquaculture/publications/species-freshwater/barramundi-aquaculture-prospects. Accessed 2016.

NSW Department of Primary Industries 2016b. Blue mussel – aquaculture prospects. https://www.dpi.nsw.gov.au/fishing/aquaculture/publications/species-saltwater/blue-mussel-aquaculture-prospects. Accessed 2016.

NSW Department of Primary Industries 2016c. Eels – aquaculture prospects. https://www.dpi.nsw.gov.au/fishing/aquaculture/publications/species-freshwater/eels-aquaculture-prospects. Accessed 2016.

NSW Department of Primary Industries 2016d. Murray cod – aquaculture prospects. https://www.dpi.nsw.gov.au/fishing/aquaculture/publications/species-freshwater/murray-cod-aquaculture-prospects. Accessed 2016.

NSW Department of Primary Industries 2016e. Starting up. https://www.dpi.nsw.gov.au/fishing/aquaculture/starting-up. Accessed 2017.

NSW Department of Primary Industries 2018. Silver perch – aquaculture prospects. https://www.dpi.nsw.gov.au/fishing/aquaculture/publications/species-freshwater/silver-perch-aquaculture-prospects. Accessed 2018.

NSW Government 2009. NSW land based sustainable aquaculture strategy. Published by Industry & Investment, NSW Government, New South Wales.

https://catalogue.nla.gov.au/Record/4903014http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/638720/NSWLBSAS.pdf

Nunes-Vaz RA 2014. Physical characteristics of Spencer Gulf. In: Natural History of Spencer Gulf (eds) Shepherd SA, Madigan SM, Murray-Jones S, Gillanders BM and Wiltshire DJ. Royal Society of South Australia, Adelaide, South Australia.

Olive PJW 1999. Polychaete aquaculture and polychaete science: a mutual synergism. Hydrobiologia 402, 175-183.

Orellana J, Waller U and Wecker B 2014. Culture of yellowtail kingfish (*Seriola lalandi*) in a marine recirculating aquaculture system (RAS) with artificial seawater. Aquacultural Engineering 58, 20-28.

Page D, Gonzalez D, Dillon P, Vanderzalm J, Vadakattu G, Toze S, Sidhu J, Miotlinski K, Torkzaban S and Barry K 2013. Managed aquifer recharge stormwater use options: public health and environmental risk assessment final report. Goyder Institute for Water Research, Technical Report 13/17, Adelaide, South Australia.

Partridge G, Sarre G, Ginbey B, Kay G and Jenkins G 2006. Finfish production in a static, inland saline water body using a Semi-Intensive Floating Tan System (SIFTS). Aquacultural Engineering 35(2), 109-121.

Partridge GJ and Creeper J 2004. Skeletal myopathy in juvenile barramundi, *Lates calcarifer* (Bloch), cultured in potassium-deficient saline groundwater. Journal of Fish Diseases 27, 523-530.

Partridge GJ and Jenkins GI 2002. The effect of salinity on growth and survival of juvenile black bream (*Acanthopagrus butcheri*). Aquaculture 210 (1). DOI 10.1016/S0044-8486(01)00817-1

Partridge GJ, Lymbery AJ and George RJ 2008. Finfish mariculture in inland Australia: a review of potential water sources, species and production platforms. Journal of the World Aquaculture Society 39, 291-310.

Patridge G, Jenkins G and Frankish KR 2003. Hatchery manual for the production of snapper (*Pagrus auratus*) and black bream (*Acanthopagrus butcheri*). Aquaculture Development Unit, South Metropolitan College of TAFE, Fremantle, Perth, Western Australia.

Pentair 2016. Recirculating aquaculture systems (RAS) technology workshop handbook. Pentair Aquatic Eco-Systems Inc, Apopka, Florida, USA.

Pentair 2017. US (MN): Pentair, Urban Organics open 87,000 sq.ft. aquaponics farm. Horti-daily. https://www.hortidaily.com/article/35311/US-(MN)-Pentair,-Urban-Organics-open-87,000-sq.ft.-aquaponics-farm). Accessed 2017.

Philminaq 2008 Annex 2. Water quality criteria and standards for freshwater and marine aquaculture. http://aquaculture.asia/files/PMNQ%20WQ%20standard%202.pdf

PIRSA 1998. Aquaculture opportunities for the far northern Spencer Gulf. Prepared by PSM Group Pty Ltd for Primary Industries and Resources South Australia, Adelaide, South Australia.

PIRSA 2001. SA aquaculture handbook 1: the selection of sites and species for aquaculture; handbook 2: culture technologies and production systems for aquaculture; handbook 3: financial factors and marketing for aquaculture; and handbook 4: aquaculture project development. Prepared by Makaira Pty Ltd for PIRSA. Primary Industries and Resources South Australia, Adelaide, South Australia. [Based on 9 booklets prepared and produced by the same organisation in 1997 titled 'Eyre Peninsula Aquaculture'.

PIRSA 2017a. Northern Adelaide Plains Agribusiness Initiative. Government of South Australia, Department of Primary Industries and Regions. http://www.pir.sa.gov.au/major_programs/northern_adelaide_plains_agribusiness_initiative. Accessed 2017.

PIRSA 2017b. Two Wells to Whyalla Economic Corridor (2W2W). https://www.youtube.com/watch?v=8Z4jt6eK71k.

PIRSA 2017c. Report supporting the aquaculture (zones – Eastern Spencer Gulf) amendment policy 2017. Primary Industries and Regions South Australia, Adelaide, South Australia. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.pir.sa.gov.au/__data/assets/pdf_file/0008/295037/report-supporting-the-aquaculture-zones-eastern-spencer-gulf-amendment-policy-2017.pdf.

PIRSA 2017d. Landbased aquaculture. Department of Primary Industry and Regions, Government of South Australia. https://www.pir.sa.gov.au/aquaculture/landbased_aquaculture. Accessed 2017.

PIRSA 2019. Zoning in: South Australia aquaculture report 2016/17. Primary Industries and Regions South Australia, Adelaide, South Australia.

PPK 2002. Technical review for SA aquaculture management plans – Phase 1. Unpublished report for Aquaculture SA. PPK Environment & Infrastructure Pty Ltd and SARDI Aquatic Sciences, Adelaide, South Australia.

PSM 1998. Aquaculture Opportunities for the Far Northern Spencer Gulf. Prepared by PSM Group Pty Ltd for Primary Indusyries and Resources South Australia (PIRSA), Bentleigh, Victoria.

Purser GJ 1996. The culture performance of the greenback flounder (*Rhombosolea tapirina*) under grow-out conditions. FRDC Project No. T93/234. University of Tasmania, Launceston, Tasmania.

Queensland Government 2016a. Barramundi aquaculture. https://www.business.qld.gov.au/industries/farms-fishing-forestry/fisheries/aquaculture/species/barramundi. Accessed 2016.

Queensland Government 2016b. Mud crab aquaculture. https://www.business.qld.gov.au/industries/farms-fishing-forestry/fisheries/aquaculture/species/mud-crab. Accessed 2016.

Queensland Government 2016c. Shortfin and longfin eel aquaculture. https://www.business.qld.gov.au/industries/farms-fishing-forestry/fisheries/aquaculture/species/shortfin-longfin-eel. Accessed 2016.

Queensland Government 2016d. Starting an aquaculture business. https://www.business.qld.gov.au/industries/farms-fishing-forestry/fisheries/aquaculture/site-selection-production/getting-started/starting. Accessed 2016.

Queensland Government 2018a. Growing and harvesting redclaw. https://www.business.qld.gov.au/industries/farms-fishing-forestry/fisheries/aquaculture/species/redclaw-crayfish/growing-harvesting. Accessed 2018.

Queensland Government 2018b. Jade perch aquaculture. https://www.business.qld.gov.au/industries/farms-fishing-forestry/fisheries/aquaculture/species/jade-perch. Accessed 2018.

Queensland Government 2018c. Growing and harvesting silver perch. https://www.business.qld.gov.au/industries/farms-fishing-forestry/fisheries/aquaculture/species/silver-perch/growing-harvesting. Accessed 2018.

Quemener L, Suquet M, Mero D and Gaignon J 2002. Selection method of new candidates for finfish aquaculture: the case of the French Atlantic, the Channel and the North Sea coasts. Aquatic Living Resources 15, 293-302.

Ramano N and Zeng C 2008. Blue swimmer crabs: emerging species in Asia. Global Aquaculture Advocate, May/June 2008, p. 36.

Rawlinson P 2004. The economics of partial and intensive Murray cod recirculation aquaculture systems. In: Development of Intensive Commercial Aquaculture Production Technology for Murray Cod (eds) Ingram BA and DeSilva SS. Final report to the Fisheries Research and Development Corporation, Project No. 1999/328. Primary Industries Research Victoria, DPI, Alexandra, Victoria, Australia. p. 167-181.

Robarra 2017. https://www.robarra.com.au/. Accessed 2017.

Roberts S, Hayward CJ and Clarke SM 2012. Addressing key aquatic animal health issues limiting production of Australian yellowtail kingfish (*Seriola lalandi*) and hatchery reared southern bluefin tuna (*Thunnus maccoyii*) industries. Australian Seafood CRC Report No. 2008/711, SARDI Aquatic Sciences Publication No. F2012/000198-1 and SARDI Report Series No. 648. South Australian Research and Development Institute (SARDI) – Aquatic Sciences, Adelaide, South Australia. 132 pp.

Roos G, Cheshire A, Nayar S, Clarke S and Zhang W 2019. Harnessing marine macroalgae for industrial purposes: emerging research and opportunities. IGI Global Publishers, Pennsylvania, USA. 280 pp.

SA Water 2017. SA Water drinking water quality report 2015/16. SA Water, Adelaide, South Australia. https://www.sawater.com.au/__data/assets/pdf_file/0003/137703/509638_SA-Water_Drinking-Quality-Report-2016_FA-142-lo.pdf

SADF 1989. Aquaculture at Port Augusta; proposal for research and development. South Australian Department of Fisheries, Adelaide, South Australia.

SADF 1991. A preliminary feasibility study: aquaculture. Report to the District Council of Wakefield Plains. South Australian Department of Fisheries, Adelaide, South Australia.

Sarre GA, Partridge GJ, Jenkins GI, Potter IC and Tiivel DJ 2003. Factors required for the successful aquaculture of black bream (*Acanthopagrus butcheri*) in inland water bodies. Fisheries Research and Development Corporation Project No. 1999/320. Centre for Fish and Fisheries Research, Murdoch University, Murdoch, Western Australia. 75 pp.

Savage J 2016. Australian fisheries and aquaculture statistics 2015. Fisheries Research and Development Corporation project 2016-246. Australian Bureau of Agriculture and Resource Economic Sciences (ABARES), Canberra, Australian Capital Territory (ACT).

Seafish and Epsilon 2002. The turbot hyperbook. Sea Fish Authority and Epsilon Aquaculture Limited. https://docplayer.net/21186650-The-turbot-hyperbook-sea-fish-industry-authority-2002-epsilon-aquaculture-limited-2002-press-for-next-page-epsilon-aquaculture-limited.html http://www.seafish.org/media/Publications/TURBOT_HYPERBOOK_SHOW_print_comp.pdf.

Shelley C and Lovatelli 2011. Mud crab aquaculture. A practical manual. FAO Fisheries Technical Paper 567. Food and Agricultural Organisation of the United Nations, Rome, Italy.

Shepherd SA, Bryars S, Kirkegaard I, Harbison P and Jennings JT (eds) 2008. Natural history of Gulf St Vincent. Royal Society of South Australia, Adelaide, South Australia.

Shepherd SA, Madigan SM, Gillanders BM, Murray-Jones S and Wiltshire DJ (eds) 2014. Natural history of Spencer Gulf. Royal Society of South Australia, Adelaide, South Australia.

Simon CJ 2009. Advancing the nutrition of juvenile spiny lobster, *Jasus edwardsii*, in aquaculture. PhD thesis, The University of Auckland, Auckland, New Zealand. 169 pp.

Smallridge 2002. Husbandry of the blue swimmer crab in aquaculture. FRDC Final Report, Project No. 1998/333. Ocean Gold Investments and Fisheries Research & Development Corporation, Canberra, Australian Capital Territory. https://www.frdc.com.au/project/1998-333.

Smallwood CB, Hesp SA and Beckley LE 2013. Biology, stock status and management summaries for selected fish species in south-western Australia. Fisheries Research Report No. 242. Department of Fisheries, Government of Western Australia, North Beach, Western Australia.

Stone DAJ, Roberts SD and Currie KL 2014. Hyper-saline condition affects growth, osmoregulation and survival of fingerlings and juvenile Yellowtail Kingfish *Seriola lalandi*. Journal of Aquaculture and Marine Biology 1(1), 00005, DOI: 10.15406/jamb.2014.01.00005

Sudrop 2017. A fresh way of growing - Redefining sustainable greenhouse production of fresh fruits and vegetables. https://www.sundropfarms.com/. Accessed 2017.

Symonds JE, Walker SP, Pether S, Gublin Y, McQueen D, King A, Irvine GW, Setiawan AN, Forsythe JA and Bruce M 2014. Developing yellowtail kingfish (*Seriola lalandi*) and hapuku (*Polyprion oxygeneios*) for New Zealand aquaculture. New Zealand Journal of Marine and Freshwater Research, 48 (3), 371-384, DOI: 10.1080/00288330.2014.930050

Taylor R 2010. Efficient algae – the next biofuel? ECOS Magazine. http://www.ecosmagazine.com/print/EC10041.htm.

Thomas CW, Crear BJ and Hart PR 2000. The effect of temperature on survival, growth, feeding and metabolic activity of the southern rock lobster, *Jasus edwardsii*. Aquaculture, 185, 73-84.

Thouard E, Soletchnik P and Marion J-P 1990. Selection of finfish species for aquaculture development in Martinique. Aquaculture 89, 193-197.

University of Tasmania 2017. It's been called the holy grail of aquaculture…Sustainable rock lobster industry now possible after 17 years of research advances. https://www.utas.edu.au/news/2017/5/15/277-its-been-called-the-holy-grail-of-aquaculture/. Accessed 2017.

Vanderzalm JL, Page DW, Barry KE and Dillon PJ 2010. A comparison of the geochemical response to different managed aquifer recharge operations for injection of urban stormwater in a carbonate aquifer. Applied Geochemistry 25, 1350-1360.

Victorian Fisheries Authority 2017a. Aquaculture. https://vfa.vic.gov.au/aquaculture. Accessed 2017.

Victorian Fisheries Authority 2017b. Murray Cod aquaculture. https://vfa.vic.gov.au/aquaculture/murray-cod-aquaculture. Accessed 2017.

Vijayan KK, Stalin Raj V, Balasubramanian CP, Alavandi SV, Thillai Sekhar V and Santiago TC 2005. Polychaete worms – a vector for white spot syndrome virus (WSSV). Diseases of Aquatic Organisms 63, 107-111.

Wallace-Carter E 1987. For they were fishers: the history of the fishing industry in South Australia. Amphitrite Publishing House, Adelaide, South Australia.

Water Connect SA 2017. Water Connect, Government of South Australia, https://www.waterconnect.sa.gov.au/Systems/SitePages/Groundwater%20Data.aspx. Accessed 2017.

Weatherzone 2017. Adelaide Climate data. Weatherzone. http://www.weatherzone.com.au/climate/station.jsp?lt=site&lc=23090. Accessed 2017.

Weinberg P, Skropeta D and Ullrich A 2011. Seaweed cultivation pilot trials: towards culture systems and marketable products. Rural Industries Research and Development Corporation (RIRDC). RIRDC Publication No. 10/184 and RIRDC Project No. PRJ-000162. RIRDC, Canberra, ACT, Australia. 35 pp.

Wu J 1990. Environmental factors affecting the survival and growth of Western King Prawn, *Panaeus latisucatus* Kishinnouye 1900 under aquaculture conditions in Spencer Gulf, South Australia. MSc thesis, Graduate centre for Environmental Studies, Uni of Adelaide, Sep 1990.

Yearsley GK, Last PR and RD Ward 1999. Australian seafood handbook and identification guide to domestic species. CSIRO Marine Research, Hobart, Tasmania.

Yearsley GK, Onley AC and Brown FK (eds) 2000. Australian seafood users manual, making the most of the world's best. Queensland Department of Primary Industries, Brisbane, Queensland.

Yufera M and Arias AM 2010. Traditional polyculture in "Esteros" in the Bay of Cadiz (Spain): hopes and expectancies for the prevalence of a unique activity in Europe. Aquaculture Europe 35, 22-25.

Zamora LN and Jeffs AG 2011. Feeding, selection, digestion and absorption of the organic matter from mussel waste by juveniles of the deposit-feeding sea cucumber, *Austalostichopus mollis*. Aquaculture 317, 223-228.

Zamora LN and Jeffs AG 2012. Feeding, metabolism and growth in response to temperature in juveniles of the Australian sea cucumber, *Austalostichopus mollis*. Aquaculture 358, 92-97.

Zamora, LN 2014. Advances for the aquaculture of the Australian sea cucumber, *Austalostichopus mollis*. PhD thesis, Leigh Marine Laboratories, University of Auckland, New Zealand. 144 pp.