DEVELOPING NORTHERN AUSTRALIA

Northern Australia Aquaculture Industry Situational Analysis

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Literature Review

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- conclusions against results
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ACRONYMS AND ABBREVIATIONS

Acronym	**Definition**
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABFA	Australian Barramundi Farmers Association
ACIAR	Australian Centre for International Agricultural Research
APFA	Australian Prawn Farmers Association
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CoOL	Country-of-Origin Labelling
CRCNA	Cooperative Research Centre for Developing Northern Australia
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAWR	Department of Agriculture and Water Resources, Australian Government (existed between 2015 and 2019; now Department of Agriculture).
DoF	Department of Fisheries, Government of Western Australia (now part of DPIRD)
DPIR	Department of Primary Industry and Resources, Northern Territory Government
DPIRD	Department of Primary Industries and Regional Development, Government of Western Australia
FAO	Food and Agriculture Organisation of the United Nations
FRDC	Fisheries Research and Development Corporation
ICLARM	International Centre for Living Aquatic Resources (now the WorldFish Center)
IRG	Indigenous Reference Group, an advisory committee to the FRDC
IUCN	International Union for Conservation of Nature
MT	Metric tonnes
NA	Northern Australia
NAC	National Aquaculture Council
NT	Northern Territory
ORIC	Office of the Registrar of Indigenous Corporations
PPA	Pearl Producers Association
QDAF	Queensland Department of Agriculture and Fisheries
QLD	Queensland
RAS	Recirculating Aquaculture System

TFK	Traditional Fishing Knowledge
WA	Western Australia
WSSD	White spot syndrome disease
WSSV	White spot syndrome virus

INTRODUCTION

Aquaculture opportunities in northern Australia

The target of Australia's National Aquaculture Strategy is to achieve a doubling of production to a value of $2 billion p.a. by 2027 (DAWR, 2017). Several sectors already farming aquatic animals and plants in northern Australia have plans for expansion, notably barramundi and prawns, making an important contribution to the projected growth of the national industry. Other sectors are poised for development, including existing industries such farming pearl oysters, redclaw and grouper (rockcod) species. There is also substantial scope to increase engagement of Aboriginal and Torres Strait Islander peoples, and to harness emerging opportunities in new species for aquaculture.

Global aquaculture

With wild-capture fisheries reaching a plateau of production in the 1980's, the aquaculture sector has continued to expand to a global production of 110.2 million metric tonnes (MT) valued at USD 243.5 billion (FAO, 2018). Aquaculture provides over 50% of the fish consumed by people worldwide. With an increasing human population, and a growing middle class, the demand for seafood is predicted to increase, placing a demand for an additional 30 million MT by 2030 (FAO, 2018).

From an Australian perspective, it is important to consider the increasing demand domestically, internationally and balance of production among low and high value products that are both profitable to produce and can be delivered to appropriate markets.

Aquaculture in Australia

Australia produced 93,968 tonnes of aquaculture product in 2016-17, reflecting 53% growth since 2006-07 (Mobsby, 2018). The national aquaculture industry was worth $1.3 billion in 2016-17 and has the fastest growth in the agri-business sector (Mobsby, 2018). However, several of the highest volume and value sectors are produced in the southern states of Australia; notably salmonids (more than doubled volume from 2006-07 to 2016-17), southern bluefin tuna, edible (Pacific) oysters and abalone. Tasmania and South Australia account for 74% of the aquaculture industry's production value. Pearl oysters, prawns and barramundi are the largest sectors with all or substantial production in northern Australia (Table 1.1. 1). Together, Western Australia, the Northern Territory and Queensland, comprise 18% of national aquaculture value.

Given the natural resources available in northern Australia, current high value species produced in the north, and many identified native species with potential for aquaculture, it is critical that the opportunities with the highest chances of success are supported to deliver expansion.

Additionally, for the national industry, and for northern Australia particularly, there is a "need for a stronger level of recognition of the rights and interests of Aboriginal and Torres Strait Islander peoples in the management and development of aquaculture in Australia" (DAWR, 2017).

Aquaculture development is supported by national, state and territory, and industry-based plans. In support of aquaculture, the Australian Federal government released a National Aquaculture Statement in 2015, which was followed by a National Aquaculture Strategy in 2017 (DAWR, 2017). In terms of Research, Development and Extension

(RD&E) the '*Success through innovation: The National Fishing and Aquaculture Research, Development and Extension Strategy 2016*' (FRDC, 2016) is in alignment with the National Strategy. For the Fisheries Research and Development Corporation (FRDC), this is operationalised through the '*Knowledge for Fishing and Aquaculture into the Future: FRDC RD&E Plan 2015-20*', and annual operational plans.

These documents also articulate with plans in the '*National Marine Science Plan 2015–2025: Driving the development of Australia's blue economy*' (National Marine Science Committee, 2015), and of special reference to this study '*Scaling up: Inquiry into Opportunities for Expanding Aquaculture in Northern Australia*' (JSCNA, 2016).

Additional review of the northern Australia aquaculture industry policy context is provided in the Stage 1 Report. The Australian Fish Names Standard is used throughout the literature review for species' common names.

1. CURRENT INDUSTRY STATUS

1.1. Overview

The production of the four major established aquaculture species in northern Australia was estimated at 10,629 tonnes for 2016-17, with a GVP of over $212 million. The industry employs approximately 700 FTE in northern Australia (DAF, 2018a; Mobsby, 2018).

Table 1.1. 1 Recent annual production, value and percentage of value of established aquaculture species farmed in northern Australia. Northern Australia (NA) production information is included where available. Percentage value of aquaculture production of established species from WA, NT and QLD.

Species	**Volume of Production (T)**	**Value of production (million AUD)**	**Value (%)**	**Region**	**Reference**
Tiger Prawn *Peneaus monodon*	3,464	78	36.7	QLD	Mobsby, 2018; 2016-17 data; Seafarms Group Ltd, pers. comm.
Banana Prawn *Fenneropenaeus merguiensis*	800	Included above	-	QLD	Seafarms Group Ltd, pers. comm.
Barramundi *Lates calcarifer*	6,300	63	29.6	QLD, NT, WA	ABFA, pers. comm., based on 90% in NA
Pearls *Pinctada maxima*	n/a	70	32.9	WA	Mobsby, 2018; 2016-17 data
Redclaw *Cherax quadricarinatus*	64.8	1.7	0.8	QLD	Mobsby, 2018; 2016-17 data
TOTAL	**10,629**	**212.7**			

1.2. Established species

1.2.1. **Marine prawns (black tiger prawn *Peneaus monodon* and Banana prawn *Fenneropenaeus merguiensis*)**

Species biology/culture characteristics

Farming of marine prawns is the largest food producing aquaculture industry in northern Australia and is focused on two cultured species, the black tiger prawn (*Penaeus monodon*) and the banana prawn *Fenneropenaeus merguiensis* (Figure 1.2.1. 1). Both species have a broad Indo-Pacific distribution and live in near-shore coastal areas, with the black tiger prawn ranging from the eastern coast of Africa and the Arabian Peninsula, to Southeast Asia, the Pacific Ocean, and northern Australia (FAO – www.fao.org/fishery/species). The banana prawn has a more limited distribution from the Persian Gulf, Southeast Asia to northern Australia. In Australia, both species are primarily tropical, inhabiting coastal areas (north of 25°S and 29°S, respectively). The black tiger prawn is the second farmed penaeid prawn globally by volume after the Pacific white legged shrimp (*Litopenaeus vannamei*), while the banana prawn is only farmed at scale in one farm in Queensland.

Growth of marine prawns is linked to temperature, with optimum growth realised above 25°C. Given the sustained higher temperatures experienced in northern Australia, farms in far North Qld can usually produce two crops a year, while those in southern Queensland are limited to only one growout.

Figure 1.2.1. 1 The black tiger prawn *Penaeus monodon* (left) and banana prawn *Fenneropenaeus merguiensis* (right).

Both marine prawn species farmed in Australia are considered fairly robust to farm, although the black tiger prawn has proven particularly difficult to domesticate due to reproductive, fertility and larval quality problems. As a result, the black tiger prawn aquaculture industry is largely based on the collection of wild-caught broodstock to produce the post-larvae for pond stocking.

Since the early 2000's there have been several major government funded projects to domesticate the species, as well as efforts by industry. These projects have not been successful in leaving a legacy of large-numbers of domesticated families. Some companies have been able to maintain a few families for several generations, but the contribution of domesticated broodstock to overall production is minor. Several companies now, however, have or are about to commence active programs to produce domesticated lines of black tiger prawn. This move is driven by the difficultly in accessing a sufficient number of wild-caught broodstock and the need to minimise risk at a time of expansion, through progress toward domesticated Specific Pathogen Free (SPF) broodstock, and securing the supply of post-larvae.

In contrast to that of black tiger prawns, banana prawns at Seafarms in Cardwell have been domesticated for over 20 years.

History of production

Farming of marine prawns in Australia begun in the 1960's based on school (*Metapenaeus bennettae*) and King prawns (*Melicertus latisulcatus*) in NSW and South Australia. In northern Australia the first farming operations were initially at Seafarms, Cardwell and Flying Fish Point (1983-1986), before expansion to Townsville and Darwin in the late 1980's. Commercial production was attempted in Derby in northern WA, however, was hindered by the prevailing aquaculture regulations and lack of investment (Ian Crimp, pers. comm.). Since this time of small-scale operations, the industry has gradually expanded to at present comprise over 900 hectares of production ponds, with major farms situated north of Yamba NSW, and clustered around the Logan River, Mackay, Bundaberg, Townsville, Cardwell, Mission Beach and Port Douglas (Figure 1.2.1. 2). All but one farm is currently located in Queensland where there are 24 active licenses, with the industry in this State expected to expand significantly due to the reactivation of several budding farms near Proserpine and Mission Beach by Tassal, along with the identification of six Aquaculture Development Areas (totalling approximately 7,048 hectares) in Queensland in 2018. In WA and NT, there is currently no pond production, although there is a major development proposed for the NT ("Project Seadragon" which aims to establish a 10,000 hectare farm over the next 10 years.) The industry is presently served by nine (9) licensed hatcheries and employs between 300-350 staff (Kim Hooper APFA Exe Officer, pers. comm).

Figure 1.2.1. 2 Present sites in Australia contributing to majority of farmed marine prawn production and where major industry hatcheries are located.

Production volumes and value of the Australian prawn aquaculture industry have steadily increased since 2007-08, with value approximately doubling to around $77.8 million in 2016-17 (Figure 1.2.1. 3). However, due to an outbreak of whitespot syndrome virus (WSSV) that severely impacted farms on the Logan River, production in 2017-18 was reduced to $74 million (DAF, 2018b).

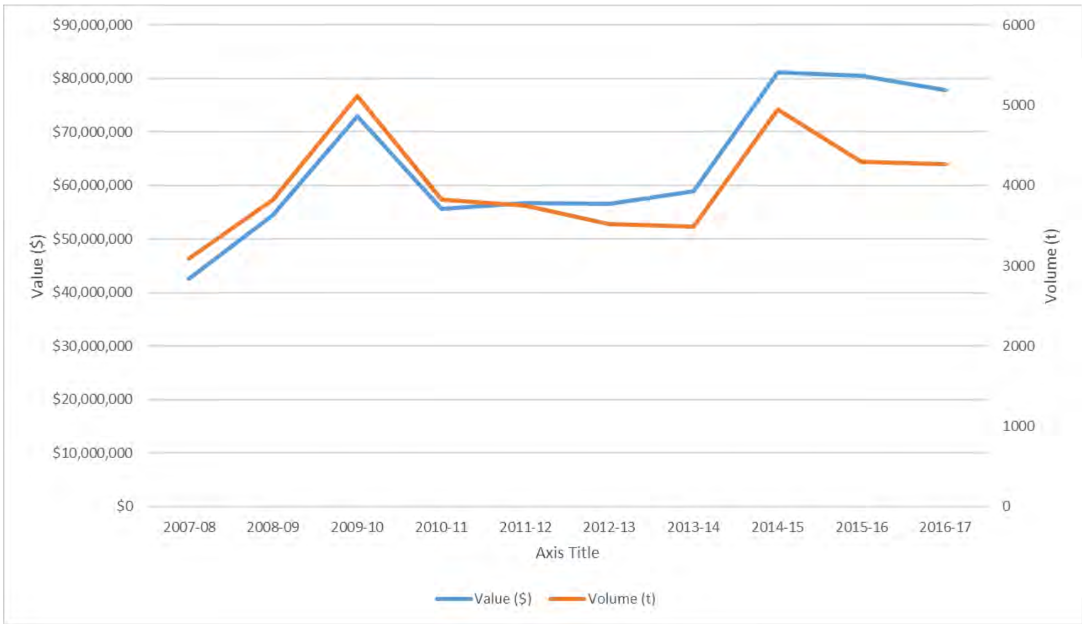


Figure 1.2.1. 3 Production volumes and associated value of Australian farmed marine prawns between 2007 and 2016. (Raw data source: Mobsby, 2018)

Research and development (R&D)

The prawn aquaculture industry, through its peak representative body the Australian Prawn Farmers Association (APFA), has long recognised the importance of investing in R&D and were the first Australian seafood sector to implement a compulsory federal levy based on production aimed at funding research and development. According to the APFA website the industry currently raises around $300,000 annually to invest in R&D. Issues to address identified by the industry through their 5 Year R&D Strategic Priorities 2015-2019 (APFA, 2015) include research into genetics and post-larvae production (especially domestication), improving farm efficiency, improved nutrition and disease and biosecurity (Figure 1.2.1. 4).

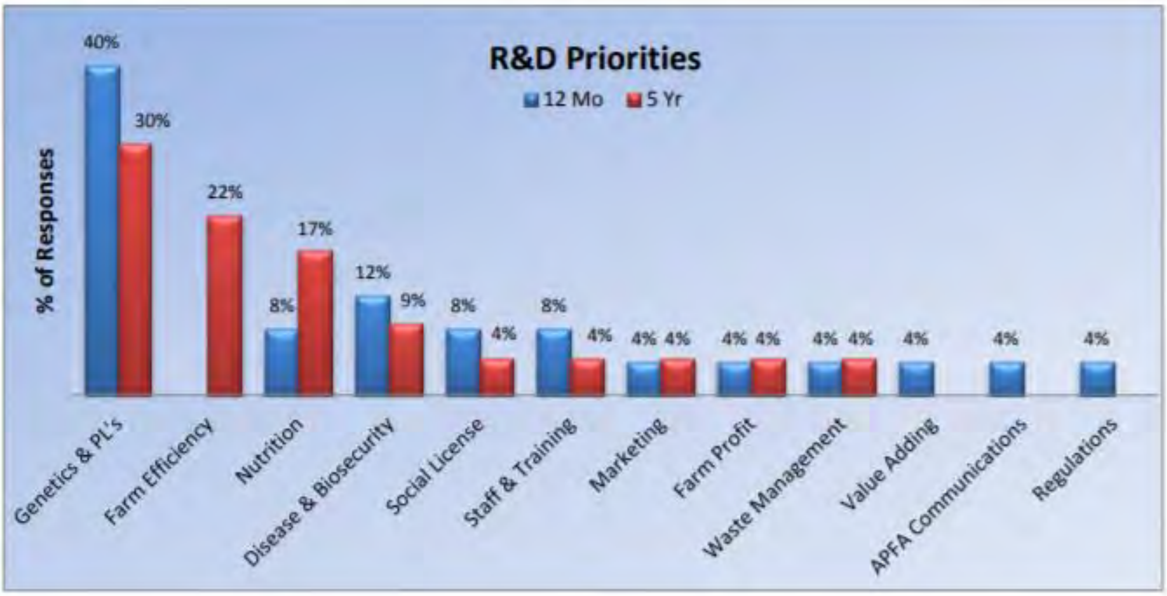


Figure 1.2.1. 4 R&D priority areas to 2019 for the Australian prawn aquaculture sector. The % of responses refers to survey answers of the APFA Executive and R&D committees. (Source APFA, 2015).

The Australian prawn farming sector has historically had significant investment in R&D over the last two decades and this is summarised in Lawley (2015). This includes substantiative research in the areas of disease, farm operations, genetics, environment and marketing. Of particular note, the FRDC with industry funded two major projects aimed at domesticating and selectively breeding the black tiger prawn (FRDC 2002/209; 2006/205) which advanced knowledge related to closing the life-cycle of the species, although the programs themselves have not lead to broad non-reliance of the industry on wild broodstock as had intended. In 2014, the Australian Research Council funded an Industrial Transformation Research Hub involving JCU, USyd, CSIRO, Seafarms Ltd and the Australian Genome Research Facility, which had as its aim to develop the genetic and genomic knowledge to allow the Australian black tiger prawn industry implement world-leading genomic based selective breeding. The learning and tools developed from the FRDC and ARC funded programs have put in place the foundation for the industry to conduct highly effective domestication and selective breeding programs when, and where, the industry is ready. Implementation of selective breeding for prawns is no longer considered an R&D impediment from a genetics knowledge-base perspective.

1.2.2. **Barramundi (*Lates calcarifer*)**

Species biology/culture characteristics

Barramundi (*Lates calcarifer*) (Figure 1.2.2. 1), also known as Asian seabass, are widely distributed in coastal and brackish waters throughout the Indo-West Pacific region from the Arabian Gulf to southern China, the Philippines, Indonesia, Papua New Guinea and Australia (Jerry, 2014). The species is endemic across northern Australia between the Mary River, eastern Queensland, and the Ashburton River, Western Australia. Barramundi is a particularly hardy species making it ideal for aquaculture, as it is euryhaline (can tolerate freshwater to full marine salinities), fast growing (reaching 3-4 kg in 24 months), weans onto an artificial pellet relatively easily around 3 weeks post-hatch, has a good food conversion ratio (<1.5:1) and can be farmed at high densities (up to 100 kg/m^3) (Jerry, 2014). Accordingly, barramundi in Australia are farmed in a variety of aquaculture systems in all mainland States, including marine seacages (WA), brackish and freshwater ponds/raceways (NT, QLD), and environmental-controlled recirculation or freshwater flowthrough systems (NSW, VIC, SA). Best performance in growth is achieved in culture conditions between 30 and 32 °C (Bermudes et al 2010; Glencross and Bermudes 2012).

Figure 1.2.2. 1 Barramundi (*Lates calcarifer*)(top) and examples of four types of culture systems employed in Australia (left to right; brackish and freshwater pond culture, marine cages, intensive recirculation systems, raceways.

History of production

Techniques to breed barramundi for aquaculture seedstock were first developed in the Songkhla Marine Laboratories in Thailand in the early 1970s. Farming was localised in Thailand and surrounding countries until 1983, when hatchery breeding technologies were trialled at the Northern Fisheries Centre Cairns, Queensland Department of Primary Industry, in an effort to develop an impoundment stocking program for Tinaroo Dam and local rivers and estuaries. In 1986, the first commercial aquaculture operation to farm barramundi was established by Sea Hatcheries Limited, Innisfail. Since this time the industry has gradually grown to represent approximately 370 license holders (Harrison et al, 2014). Most of these registered farms are not commercial producers of barramundi, however, but have the species attached to their licenses in Queensland if they hold or stock barramundi into farm dams. Production volume of barramundi is primarily dominated by nine companies, which produce ~95% of Australian grown product (ABFA webpage). Figure 1.2.2. 2 shows where the current major barramundi producers are located.

Figure 1.2.2. 2 Present sites in Australia contributing to majority of farmed barramundi production, including production systems used and where major industry hatcheries are located.

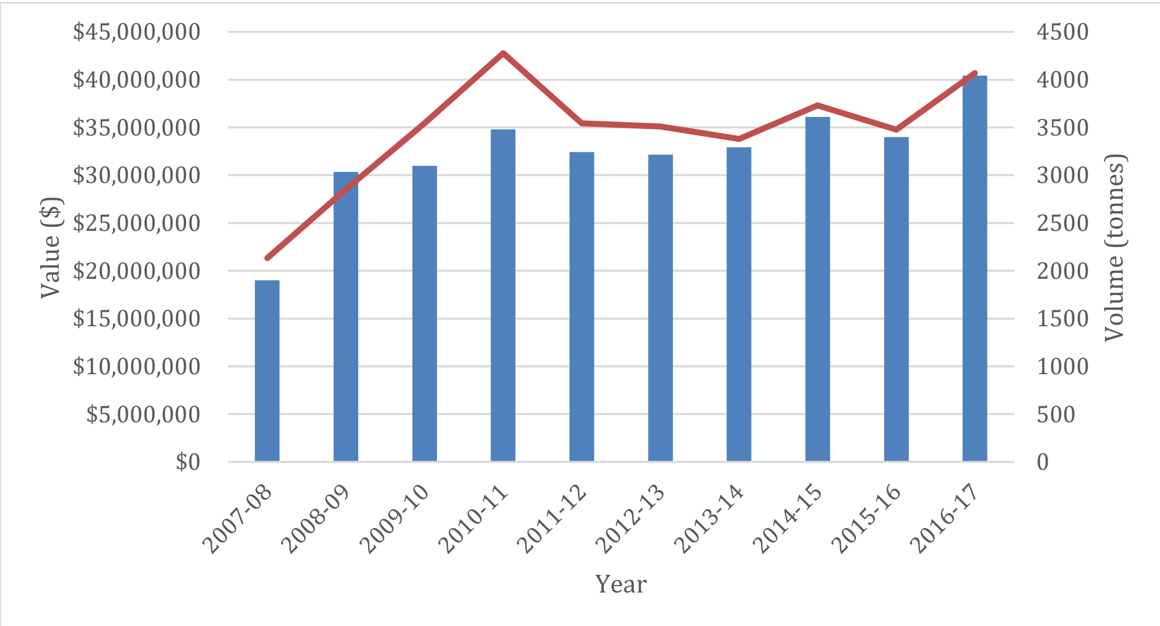


Figure 1.2.2. 3 Production of barramundi in Australia from 2007-17. value ($)– bars; Volume (tonnage) – line (Source raw data: Mobsby, 2018).

The majority of farmed barramundi historically and continues to originate from Queensland (~50%) (Figure 1.2.2. 3), although rapid expansion of farms at Humpty Doo, Northern Territory and Cone Bay, Western Australia, are resulting in increasing production volumes. In 2017, the industry reported 4,000 tonnes of fish valued at $40 million (Mobsby, 2018) (Figure 1.2.2. 4). However, the peak association representing the industry, the Australian Barramundi Farmers Association (ABFA), states that the industry currently produces 7,000 tonnes ($70 million) annually (ABFA website). This figure is likely more accurate given farms in the Northern Territory and Victoria do not have their production data included in 'farmed barramundi' statistics due to confidentially concerns arising from being the sole producers in each State/Territory. The 7,000 tonnes of barramundi grown annually is derived from only ~170 ha of ponds/raceways/seacages, or tank-based production systems. 90% of this production originates from farms in northern Australia.

Market

The market for barramundi in Australia is estimated to be around 16,000-20,000 tonnes per year (~>AU$120 million), with only 8,500 tonnes locally sourced (~1,500 tonne wild caught, 7,000 tonne farmed) (Harrison et al., 2014; ABFA, 2015, Jo-Anne Ruscoe pers.comm). The remaining ~11,500 tonne is imported product primarily from Thailand, Vietnam, Singapore, and Indonesia. This is a major concern for the local industry, as Australian consumers associate the name 'barramundi' with Australian product despite the majority of *L. calcarifer* sold in Australia being imported. In addition, Country-of-Origin Labelling (CoOL) at the point of sale is limited in Australia, making it difficult for customers to determine the product source. At present, there is no substantiative export of fillet or whole fish, although Australian hatcheries are one of the biggest suppliers of high-quality fingerlings to farms in southeast Asia, Middle East, USA and Europe.

Barramundi is grown to various sizes to meet market demand and needs, but there are two basic size classes – plate sized (under 1.0 kg), or whole large fish (2.5 kg plus). Most of the farms in northern Australia target production of large fish (2.5 kg+) which are sold whole to wholesaler, retailers and food service providers. The domestic market price (farm-gate) is around $10/kg. Southern producers generally focus on the plate sized fish market, selling live into markets and to restaurants in Sydney, Melbourne and Adelaide (Harrison et al, 2014). The ABFA predicts (from member survey results) that the Australian industry will produce at least 10,000 tonnes of fish by 2020 (ABFA, 2015).

The barramundi industry in northern Australia directly employees ~150 people annually in regional areas.

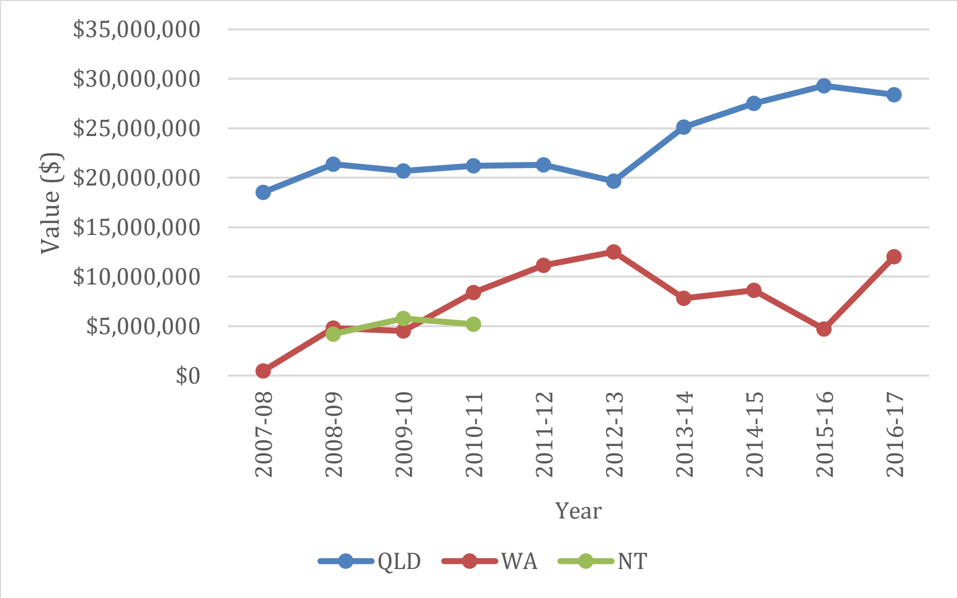


Figure 1.2.2. 4 Barramundi production between 2007-17 by State. Note: data only includes production figures for QLD, NT and WA, and for NT only up to 2010 (due to only one farm producing in the NT and confidentiality reporting arrangements) (Source raw data: Mobsby, 2018).

Research and development (R&D)

Through its representative body ABFA, the Australian barramundi industry, has identified seven key investment areas for R,D&E (ABFA, 2015). These R,D&E areas are summarised in Table 1.2.2. 1 and broadly encompass investment into market differentiation of Australian product, production of quality product, sustainable production, biosecurity and management of risk, understanding farm productivity and regulatory constraints and their impacts.

Table 1.2.2. 1 Strategic research, development and extension priorities for the Australian Barramundi Farmers Association (Source: modified from ABFA, 2015).

Investment priority	Objective
Market differentiation for Australian barramundi	-Naming rights for 'Barramundi' for Australian produced *Lates calcarifer* - Branding and promotion program for Barramundi - Differentiate Australian caught or grown (produced) barramundi vs imported *Lates calcarifer*.
Consistent high-quality Australian product to meet consumer preferences	-National ABFA Quality Scheme (QA) - Cool chain management and product integrity adopted along whole supply chain
Effective management of biosecurity risk	- Understanding of biosecurity risks and processes to minimise those risks. - AQUAPLAN is adequate to deal with emergency response to a disease outbreak in industry -Off-label treatments
Awareness of farm productivity and management options	- Better awareness of farm productivity issues and options
Sustainable barramundi production systems	- Understand the level of regulation seeking to address sustainability - Strategy to address unnecessary burdens - National strategy to manage water discharge
Effective regulatory frameworks to support Australian barramundi farms	- Understand level of regulations in place impacting on barramundi aquaculture - Promote ABFA members environmental sustainability
A resourced national industry body that delivers outcomes	-ABFA business and communication plan -Solid governance structure -Capacity building

1.2.3. Pearls

Species biology/culture characteristics

The silver-lipped pearl oyster (*Pinctada maxima*) is a tropical bivalve species of the Pteriidae family, which are widely distributed throughout tropical waters of the Indo-West Pacific region, from the Bay of Bengal in the west, to the Solomon Islands in the East. (Figure 1.2.3. 1; Travaille et al., 2016). Across Australia, the species is commonly found in tropical shallow coastal waters north of Shark Bay Western Australia (~25°S), across northern Australia to Cooktown Queensland, and south down to the Cairns region (~16°S) (Wada & Temkin 2008). Five other recognised pearl producing oyster species are also co-distributed across this region including; *Pinctada albina, P. fucata, P. maculata, P. margaritifera and Pteria penguin,* although the silver-lipped pearl oyster, *P. maxima,* is the only primary cultured species in Australia (Wada & Temkin 2008).

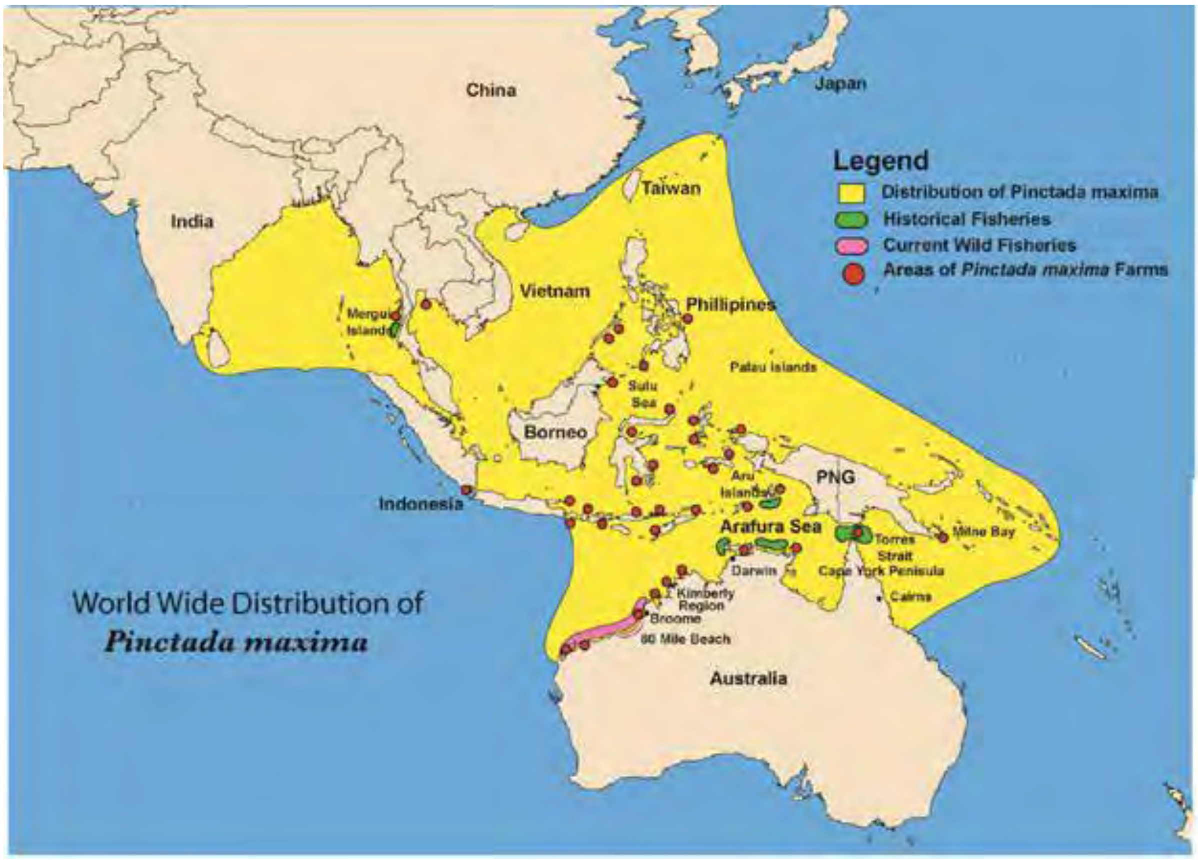


Figure 1.2.3. 1 Geographical distribution of Silver-lipped pearl oyster and areas of historical and current fisheries including known farms in 2016 (Travaille et al. 2016).

Pinctada maxima is a filter feeder and suitable sub-tidal habitat is characterised by strong tidal currents typically between 5 to 50 m depth comprised of sea beds, where there is a hard substratum on which oysters attach themselves. Silver-lipped pearl oysters are a protandrous hermaphrodite broadcast spawner, whereby their life cycle includes a planktonic egg and larval stage of 28 to 35 days (Saucedo and Southgate 2008). Oysters grow quickly with males maturing at 3-4 years old at a length of 100 - 120 mm. In the same age class at approximately 170 mm in length around half the oysters are females and most oysters larger than 190 mm are females. Synchronous spawning generally occurs between September and May each year, whereby females are highly fecund, producing millions of eggs. Recruitment and dispersal of oyster larvae is primarily driven by environmental factors (i.e., wind and ocean current conditions) (Saucedo and Southgate 2008). The planktonic oyster larvae metamorphose through several life stages over about 28 days before they settle and change to juvenile oysters or "spat". The spat require a hard substrate to settle on and anchor to and do not move after this period. The genetic connectivity of *P. maxima* was more recently investigated by Lind et al., (2007) with results indicating that genetic diversity and gene flow decreases with geographical distance from central Indonesia. An observation also supported by Benzie & Smith-Keune (2006) suggests that the Indonesian populations provide limited direct recruitment to Western Australia (WA) or Northern Territory (NT) populations. Within Australia, low levels of regional genetic structuring were observed, with WA stocks differentiated the most from that of northern east coast Australian populations. Furthermore, when Benzie & Smith-Keune (2006) compared WA and NT populations there was some evidence of genetic partitioning, although this was weak with strong gene flow generally observed across adjacent local populations.

Hatchery and farm characteristics

The Australian pearling industry is currently comprised of three integrated major activities including; the collection of pearl oysters from the wild, the production of hatchery reared pearl oysters, and the seeding of pearls for growout. Following selection of suitable wild or farm-reared broodstock, animals are induced to spawn (ie., through thermal stress and/or frozen sperm), with the fertilised eggs stocked into tanks of filtered seawater (Southgate 2008). Following metamorphous from egg to larvae (approx. 24 hr), microalgae are added to the rearing tanks and water changes are conducted every 2 to 4 days. Around 24 to 28 days from spawning, larvae metamorphose into spat and settlement occurs on collectors hung inside the tank. Spat are commonly held until they are large enough to be placed into mesh nets or other structures at around 20 to 50 mm in length, whereby they are transferred to larger net panels on surface longlines in the ocean (Southgate 2008). The quality of the water and stability of environmental conditions are an important factor in successfully rearing animals to adult size. As the oyster grows and increases in size they are routinely cleaned of biofouling and transferred to progressively larger nets. The time required for a pearl oyster to reach a "seedable size" (ie., size at which pearl seeding is conducted) for cultured pearl production is between 2 to 3 years. It then takes an additional 1.5 to 2 years to develop a cultured pearl to commercial size for harvest. Oysters are routinely seeded at least twice before their disposal. Within Australia, WA, NT, and QLD government legislation and policy guidelines primarily govern the development, wild collection, translocation, health testing and hatchery requirements, including minimum standards for commercial pearl oyster hatcheries.

Overview of production in Australia

Historically, the most productive fisheries of *P. maxima* have been within the Arafura Sea between Australia and Indonesia (Figure 1.2.3. 1). Today, the only viable managed wild fishery of *P. maxima* remaining is in Western Australia (WA) (Figure 1.2.3. 1), which is separated into four zones extending from Exmouth WA (114°S 10°E) to the Northern Territory border (128°S 15°E) (Fishery Management Paper No. 276, 281, 289).

Management of this fishery is based on a WA government quota system incorporating size limits, data collection, compliance monitoring and hatchery operations. Today the Australian *P. maxima* pearl industry currently relies on the collection of wild-caught pearl oyster from WA zones for the majority of the oysters used for pearl production, although some hatchery produced animals are now utilised to supplement the wild animal quota. Within WA *P. maxima* fishery zones, oysters are almost exclusively caught from Eighty Mile Beach, south of Broome (Fishery Management Paper No. 281, 289). The production of *P. maxima* pearls requires pristine conditions, whereby animals must be reared in clean, nutrient rich tropical waters. The mega-tidal waters of northern Western Australia (particularly from Roebuck Bay to Northern Kimberley) and other farms located in parts of the Northern Territory produce these highly desirable environmental conditions and as such produce superior quality pearls (Jelbart et al., 2011). Consequently, Western Australia and the Northern Territory are the only remaining Australian locations where an active viable *P. maxima* pearl oyster industry is found (e.g., Paspaley Pearling Company, Cygnet Bay Pearls, Clipper Pearls, Maxima Pearling Company, Willie Creek Pearls, Ellies Pearling, Arrow Pearl Co. and Norwest Pearls). However, there are a few small farms remaining in the Torres Strait in far north QLD (e.g., Roko Pearls, Torres Pearls, and Kazu Pearls), although these are mainly focused on eco-tourism activities.

Pearl oyster industry statistics and metrics

The Australian *P. maxima* pearl oyster farm industry is currently valued at about $70 million per annum (ABARES 2018). In the recent past, this gross value has been as high as $122 million per annum (i.e., year 2006-2007), but has been steadily declining for more than the past decade due to both economic and production limitations (see Figure 1.2.3. 2 and Key Industry Challenges section below). At present, the vast majority of pearl farm production and value is located in the Kimberley region in WA, while the remainder comes from a limited number of small operations in the NT. There is currently over 65,000 hectares of pearling lease (open water and aquaculture farms) located across the north-west WA bioregion (i.e., Exmouth Gulf) and north-coast NT bioregion (i.e., Pilbara and Kimberley coasts) (Fletcher et al., 2006).

Figure 1.2.3. 2 Australian pearling industry gross value of product from 2006 to 2014 (AVC Report 2017).

The pearling industry in WA is the most valuable aquaculture industry in the State and represented 78% of total aquaculture production value in 2016-2017 (~$70 mil; ABARES 2018). Over the past 12 years the value of the WA pearl production has declined by more than 51% ($122 million in 2006-2007 to $61 million in 2013-2014; ABARES 2018) primarily due to the reduction in the value of pearls following the global financial crisis in 2007-2008. Within WA, pearl farms are mostly located in the remote Kimberley region of northern WA, although there are a few leases as far down as Exmouth Gulf.

The NT pearling industry in 2008-2009 grew from $16.3 million to $20.97 million in 2010-2011 (ABARES 2018), before declining rapidly following the global financial crisis. There is currently no recorded pearl production from the NT from 2013 on-wards. Based on available information, pearl aquaculture production value represented between 53% and 78% of total NT aquaculture production between 2008-2011 (ABARES 2018). Across the NT, pearl farms are currently distributed along the northern coast in three main areas: Bynoe Harbour, Cobourg Peninsula and Truant Island (Figure 1.2.3. 1). In 2009, during the more productive years, approximately 98 people were directly employed in pearl farming or farm-related activities in the NT (Barton 2009). Since then, the effect of the global economic crisis has resulted in further rationalisation of employment.

Key Pearl Oyster Industry Challenges

Over the past decade, the Australian pearling industry has faced several critical challenges. These include economic impacts, juvenile oyster health issues, unknown effect of oil and gas industry, marine operations qualifications, marine park reserves, adequately trained staff and visa reform, future opportunities, product labelling, hatchery propagation, key production traits and selective breeding programs. All are discussed below (see AVC Report 2017; PCA Report 2016; Fisheries Management Paper No. 276 2016; Fisheries Management Paper No. 281 2016; and Travaille et al., 2016 for more detail).

Economic impacts – The global financial crisis in 2007-2008 had an immediate impact on the demand and price for discretionary luxury products worldwide which severely impacted pearl commodity trades. Furthermore, in more recent years there have been compounding factors reducing the production value of pearls and include the rapid emergence of low-cost Asian pearls and increased cost of labour and infrastructure limitations in remote locations of Australia.

Juvenile oyster health issues – Since 2006-2007 the Australian pearl oyster industry has suffered significant mortalities of juvenile *P. maxima* animals due to an emerging disease, Juvenile Oyster Mortality (JOM). JOM has resulted in lost stock and revenue and the closure or sale of a number of farms. Juvenile Oyster Mortality (JOMs) disease is a major issue for the industry and continues to impact farms with up to 95-100% of juvenile hatchery oysters dying as a result in any year of the hatchery production cycle.

Unknown effect of oil and gas industry – Increased seismic survey activity in the Exmouth and Kimberley coast area has raised concerns regarding the potential yet unknown effect on pearl oyster health, recruitment and ecosystem structure. The industry is concerned that these surveys pose a significant risk to long-term sustainability of the natural *P. maxima* resource and subsequent pearling industry. Currently there is work funded by the Pearl Producers Association to try and better understand the impacts of such seismic testing on the health and wellbeing of pearl oyster beds (Aaron Irving, PPA Exe officer, pers. comm).

Marine operations qualifications – A significant burden is placed on companies by the over-regulation of work practices that can affect critical operations. The potential removal of maritime operations “tickets” that allow for low-complexity aquaculture operations poses a significant operational risk to the industry. The industry seeks to achieve support from the government to reduce these risks, while achieving sensible, practical and fit for purpose workplace regulations.

Access to oyster beds for seedstock – Almost the entire pearling industry in WA (except Eighty Mile Beach) is incorporated within a Marine Reserve Park which allows farming activities. Although much of the pearling industry has been expressly provided for within these zones, many critical areas have less assurance, such as Eighty Mile Beach where the majority of seed oysters are collected from by the industry. Given the importance of this area for the pearl oyster industry, lack of robust assurance poses a significant risk.

Adequately trained staff and visa reform – Due to the remoteness of many pearl oyster farms and the current shortage of domestic skilled and experienced aquaculture staff, the pearling industry is struggling to adequately source trained staff that remain in regional areas. This is further exacerbated by the new limits on skilled migration programs through government visa changes that prevent the entry and retention of experienced aquaculture practitioners. This poses a significant risk to the industry both in labour costs, but also maintaining critical staff mass to uphold farm operations.

Future Outlook & Opportunities

The Australian pearl oyster industry produces a highly valued commodity that is yet to reach its potential. Consequently, there is a renewed enthusiasm from key stakeholders and governments for the revitalization and continued development of the industry in northern Australia (see for example AVC Report 2017; Travaille et al., 2016). In addition to addressing the above key challenges in the pearl industry, there are several opportunities and/or new directions that may further assist the pearling industry development in northern Australia. These include:

Product Labelling - Australia has consistently produced the world's highest quality of *P. maxima* pearls. However, without internationally recognised labelling of Australian pearls and product, the long-term value is lost and allows international suppliers to falsely label products as Australian. As with other aquaculture products, there is an opportunity to formally identify Australian pearls and create ongoing value to the industry.

Research into JOMs – A thorough understanding of the disease mechanism that causes JOMs is an important step in limiting the impact of this disease on the industry. Research partnerships are currently in place to address this need (see Developing Northern Australian Implementation report 2018) but given the difficulty in identifying the agent further research is urgently required. Once JOMs has been mitigated, there is the opportunity to limit risk and improve value through hatchery propagation of animals required for seeding and selective breeding programs.

Hatchery propagation of pearl oysters – Hatchery-based production of pearl oysters removes the legislative limits imposed on wild caught oysters and corresponding risks of obtaining animals through pearl oyster fisheries as identified above. Furthermore, it alleviates pressure on wild stocks and limits costs and loss of animals associated with transporting wild stock. Most farms in WA are situated a significant distance from the WA pearl oyster fishery ground. Currently, hatchery-bred pearl oysters form only a small proportion of WA pearl farm stock, while the majority of stock in the NT are from hatchery bred animals.

Understanding key production traits and genetic contribution – Having increased knowledge into the effect of host / donor oyster and environment on key production traits (ie., pearl quality) can lead to improved farming operations and seeding of oysters to obtain maximum value. Currently, there has been some research into the underlying genetic basis of pearling traits, although the full role the host and donor oyster each play in production of a gem-quality pearl hasn't been fully elucidated (see Jones et al., 2017).

Establishing selective breeding programs – The implementation of selective breeding programs in other animal production and aquaculture species has been highly successful in increasing productivity and value. Correctly managed selective breeding programs allow not only for improvement in key production traits in pearl oysters (ie., pearl quality and oyster growth), but also an alternate mechanism to identify and select JOMs resistant animals. Anecdotally, there appears to have been several breeding programs that have been instigated for Australian pearling companies focused primarily on pearl quality.

However, there has been no coordination among these breeding programs and many companies have not been able to sustain the costs associated with such programs. The genetic progress achieved in these breeding programs has also not been broadly communicated limiting knowledge of whether they have been successful in driving productivity performance. Of more and immediate need in regard to selective breeding is a breeding program targeting JOMs tolerance, as this syndrome is currently posing a high risk to the future viability of the pearling industry. In response to this James Cook University, Cygnet Bay Pearls and Ellies Pearls, funded by the Australian government's CRC-P program, have commenced a project to understand if JOMs tolerance can be bred for and to establish the first foundation families tolerant to the syndrome.

1.2.4. **Redclaw - *Cherax quadricarinatus***

Species biology/culture characteristics

Redclaw, *Cherax quadricarinatus*, is a species of freshwater crayfish native to the rivers of northwest Queensland, the Northern Territory and southeastern Papua New Guinea (Figure 1.2.4. 1). Although well known to the locals of this isolated region of tropical Australia, the species remained effectively unknown to the rest of Australia until the late 1980s.

Redclaw is advantaged by a host of physical, biological and commercial attributes which make it an excellent candidate for aquaculture. It is a robust species with broad geographic potential, is simple to breed, has an easy hatchery culture phase and straight-forward production technology, requires simple foods and is economic to produce. The texture and flavour of the flesh compare favorably with other commonly eaten marine crustaceans and, due to its visual similarity to lobster, is positioned at the premium end of the crustacean market spectrum. Current wholesale market price in Australia is in the range of $25 to $35 per kg.

Production has remained around 100 t per year for the past decade, and nearly all is marketed domestically (Clive Jones, pers. comm). The growth potential for the industry lies with the substantial export demand, particularly from China. In accordance, there is a small, but developing market, for export of craylings based out of Townsville (Lisa Elliott, Australian Crayfish Hatchery, Townsville, pers. comm).

Redclaw's excellent aquaculture attributes have seen it translocated to many other countries (i.e. Ecuador, China, Israel, Thailand) where commercial production has been sought, although there is no substantial production yet reported. In the longer term, Australia will maintain a production advantage based on access to the broad genetic pool of native stocks, sustainability due to strict environmental regulations, and isolation from recognised diseases like the crayfish white plague (*Aphanomyces astaci*) which have decimated crayfish populations in other countries.

Redclaw aquaculture in Australia is poised for significant expansion. The basic resources of suitable land and water are readily available throughout northern Australia and could potentially support production of several thousand tonnes. The challenge for the industry is to increase production, through expansion and new investment, to a point where the substantial quantities required by identified export markets can be supplied consistently.

Production technologies are at a stage where 'best practice' methods have been identified. These technologies are relatively straightforward and the skill levels required of practitioners are not onerous.

The harsh physical extremes of the redclaw's native habitat have conferred it broad climatic tolerances. Its preferred water temperature range for >70% of maximum growth rate is 23–31 °C. Reproduction will occur only while water temperature remains above 23 °C and day length is greater than 12 hours. While suitable temperatures prevail throughout Queensland during summer, the shorter and less extreme winter period in more northern areas offers a significant advantage. Most industry growth is expected to occur north of Bundaberg, including parts of western Queensland, the north of the Northern Territory and the Kununurra region of Western Australia.

Redclaw aquaculture requires earthen ponds which hold water. Consequently, the soil must have a reasonable clay content and be free of rock, or must suit the installation of a synthetic pond liner. Ponds are typically 1000 m^2, with a depth of between 1.0 and 2.5 m. Their specification and design can have an important bearing on productivity. Productive topsoil can be beneficial when applied across the clay-base of a pond, but it must be free of pesticides which may be highly toxic to crayfish. Water may be sourced from surface supplies or underground. Generally, water suitable for watering livestock is suitable.

Up until recently, redclaw farms generated their own seedstock through managed reproduction in the ponds. However, new hatchery technology has been developed to mass produce craylings for supply to growout farms. This involves stripping fertilised eggs from females and incubating them in a tank system until hatching. The seedstock are held in the system for two moults until the third instar crayling is produced. These are then suitable for packing and transport to growout farms (Stevenson et al., 2013). Although successful in producing large numbers of craylings, the production results from ponds stocked with craylings are highly variable, and a nursery stage will be necessary to generate advanced juvenile crayfish for pond stocking.

Growout is performed in earthen ponds, furnished with artificial habitat made from poly pipe, a necessity allowing individuals to hide from predators and during moulting. Best practice ponds are fenced and netted to minimise losses from natural predators including cormorants, night herons, water rats and eels. Feeding is generally with natural grains and other organic inputs to stimulate productivity. Redclaw are general omnivores, consuming plant and animal material and micro-organisms. Formulated diets are available, but not especially effective. Further development of manufactured diets is a research priority. Growout is typically performed for 9 to 12 months to generate marketable redclaw of 70 to 120 g in size.

Redclaw has also been subject to genetic improvement through two targeted breeding programs. The first was instigated by the Queensland Dept of Primary Industries (QDPI)(Jones et al., 2000) in 1994 and continued for four generations. This program achieved a modest improvement of 9.5% over wild stocks. While this growth improvement was less than that seen in other freshwater crayfish species like the freshwater yabby, *C. destructor*, where growth improvements of around 30% were seen after two generations of selection (Jerry et al., 2005), this initial breeding program demonstrated that increased productivity could result from genetic improvement of redclaw. Consequently, improved 'Walkamin' stock was disseminated to the redclaw industry. However, despite the potential of the improved Walkamin stock to boost production, lack of subsequent industry growth and government investment saw the breeding program terminated in 2003, without the program being efficiently transferred to commercial industry. As a result, the initial genetic gains made through the QDPI breeding program were eroded and lost through unmanaged commercial breeding practices. Subsequently, RIRDC funded a project in 2010 coordinated by James Cook University which consolidated a new foundation population (including that of the QLD DAF strain and wild stocks) and improved growth by ~16% over two generations of breeding (Stevenson et al. 2013). This strain was disseminated to industry and is currently the germplasm the majority of the northern Australian industry is based on, although again there are concerns about how genetic diversity and inbreeding are being managed currently within the industry (Jerry, pers. ob)

Figure 1.2.4. 1 Redclaw crayfish *Cherax quadricarinatus*

Comment on Research and development (R&D)

Large scale, profitable redclaw aquaculture in northern Australia can be successfully established if existing production technology bottlenecks are resolved. Industry has identified targeted research in three areas as being critical to expansion of the industry; a) development of a practical and economic diet formulation, b) up-scaling novel juvenile hatchery technology and c) improved nursery practices to generate mass production of advanced juveniles.

Economics and Opportunity

A business plan prepared by the Queensland Government (Bitomsky, 2008) provides a comprehensive scoping analysis of the redclaw aquaculture opportunity. Detailed cost-benefit analysis of redclaw farming has been performed, revealing significant economy of scale. Capital costs are moderate and operating costs relatively low, with farms of 4 ha (of ponds) or greater the most profitable. Most of the existing redclaw farms are less than 4 ha in pond area, as a result of aquaculture regulation in Queensland that would necessitate additional compliance costs for farms over 4 ha. New investment should be sought for larger farms. Redclaw aquaculture is well suited to an integrated approach where water effluent from harvested ponds is utilised for crop irrigation. Market analysis suggests production in excess of 1000 t would find ready markets, both domestically and for export.

1.3. Emerging Species

1.3.1. **Crustaceans - Cherabin (*Macrobrachium spinipes*)**

Species biology/culture characteristics

Global aquaculture of the giant freshwater prawn *Macrobrachium rosenbergii* reached 220,000 tonnes in recent years. Cherabin, an Australian native freshwater prawn formerly considered as the 'eastern form' of *M. rosenbergii* is widely distributed across northern Australia and its wild populations have been regularly harvested by locals as a delicacy. Ng and Wowor (2011) recently identified Cherabin as a different species to *M. rosenbergii* and gave it a new name, *M. spinipes*. Within Australia, analysis of mitochondrial Deoxyribonucleic Acid (DNA) revealed that wild stocks of *M. spinipes* can be categorized into four genealogically distinguished lineages, i.e. Western Australia (lineage I), Gulf of Carpentaria/Northern Territory (lineage II), Irian Jaya (lineage III) and Papua New Guinea/North east Cape York (lineage IV) (De Bruyn et al., 2004). Morphologically, Cherabin highly resembles *M. rosenbergii* and the species can grow up to 32 cm in length and 500 g in weight. Because Cherabin has not been successfully commercially farmed in Australia, there is a lack of information on culture characteristics. However, due to its taxonomic relatedness to *M. rosenbergii*, it is expected that the general culture conditions should be similar to those of *M. rosenbergii,* which has been extensively documented (e.g. New, 2002) and widely commercially grown.

History of production

Attempts to culture Cherabin in the last century, mostly in WA, all failed, reporting various problems including low larval survival, excessive cannibalism, lack of technical expertise and infrastructure to produce postlarvae consistently, and disease. In 1988, a pilot hatchery (Northern Tropical Hatcheries) was established in North Queensland to provide Cherabin juveniles to local farmers to stock their farm dams, this facility operated for three years. Broodstock for this venture were sourced from the Gilbert and Mitchell river systems in the western Gulf of Carpentaria (Greg Smith, pers. comm.). Research was conducted at James Cook University (JCU) during the late 2000's to develop hatchery and nursery techniques for the lineage II Cherabin from north QLD. This research was supported by a James Cook University internal grant and subsequently as a component of an Australian Centre for International Agriculture Research (ACIAR) grant on developing promising indigenous fish species in Northern Australia (NA) (Graham, et al., 2012). This lineage II from north QLD showed promising outcomes including: 1) consistent high larval survival (> 60%) to postlarvae (Figure 1.3.1. 1A); 2) reasonably easy nursery culture with no major cannibalism issues; 3) a pond growout trial illustrating that Cherabin could grow to a large size (60-220 g) in 8 months (Figure 1.3.1. 1B); and 4) simple growout management with low labour and feed inputs, i.e. no formulated diets required, but only regular pond fertilization after the first 2 weeks (Graham, et al., 2012).

A  B 

Figure 1.3.1. 1 A) Settled Cherabin post-larvae in a nursery tank at JCU; B) large Cherabin (> 60g) harvested after 8-month pond growout at Walkamin Research Station, Atherton Tablelands.

However, it was also noticed that harvested Cherabin showed heterogeneous growth and formed two distinct size groups categorised as: large (60-220 g) and small prawns (<10 g), with the latter far more dominant in number. This suggests that improved feeding and management is required for improving growout productivity.

Based on the results from JCU research, it is recommended that future Cherabin aquaculture R&D should focus on the growout phase, aiming at producing large prawns (> 60 g) for high-end markets (e.g. restaurants); hence not competing with the marine prawn industry. Additionally, since there are four genealogically distinguished lineages of Cherabin present in Australia and their biological characteristics could be different, it may be worthwhile to compare and evaluate aquaculture potential for each lineage.

Comment on Research and development (R&D)

R&D conducted at JCU on Cherabin encompassed broodstock management (broodstock reproductive seasonality; fecundity; and induction of out-of-season spawning); development of larval culture protocols (comparing 'green water' vs 'clear water' methods; larval stocking density and nutrition; optimizing procedures for acclimating postlarvae to freshwater); nursery techniques (optimal stocking density and utilising shelters to reduce cannibalism) (Lober and Zeng, 2009; Lober, 2015); and identifying potential disease problems (Owens et al, 2009). The research has led to hatchery techniques being relatively well established with the capacity to consistently produce millions of postlarvae for pond stocking.

Despite persistent interests, the development of Cherabin aquaculture had until recently not received any major R&D funding support. Indeed, even the ACIAR funding that supported JCU research was only a small component of a bigger project covering multiple species with emphasis on barramundi and redclaw. In 2018, the CRCNA announced funding for 3 years of a "Cherabin aquaculture production" project to develop Cherabin aquaculture in northern Australia. The project is a collaboration between North Regional TAFE's Broome Aquaculture Centre and traditional owner led businesses in WA and encompasses all phases of the production from hatchery to growout. This ongoing research will hopefully lead to major breakthroughs and the emergence of Cherabin aquaculture in northern Australia, establishing a prime new seafood product, creating jobs and generating incomes particularly for remote and Indigenous communities.

Market

Market investigation has been undertaken in collaboration with Traditional Owner groups in WA. The product is suitable as a large prawn (>60g) sold directly to restaurants, with the potential to attract $35/kg, especially for product with Traditional Owner branding and provenance (Amanda Garner, pers. comm.).

1.3.2. **Crustaceans - Tropical Spiny Lobster *Panulirus* species**

Species biology/culture characteristics

Lobsters are some of the most highly prized and valuable seafood products in the world (Plagányi et al 2018), many fisheries are overexploited (FAO 2018) and demand for the product is increasing (Pereira and Josupeit, 2017). The ability to provide additional product into the market is at present severely constrained with future opportunities likely to come from the establishment of a closed-cycle aquaculture sector for spiny lobsters. At present the production of an aquaculture product is restricted to the farming of tropical spiny lobsters to a marketable size using seedstock (puerulus and early juveniles) sourced by collecting animals from the wild (Jones 2009). Lobster growout is primarily undertaken in Vietnam, with some development in the surrounding South East Asian regions of Indonesia and the Philippines (Jones 2009; 2010). The largest market for ongrown tropical lobsters is currently mainland China and Hong Kong (Annette Tilbrook, pers. comm.); more information will be available in the CRCNA project 'Capturing the ASEAN Agricultural opportunity for northern Australia', led by the Australia-ASEAN Chamber of Commerce (AustCham ASEAN, Singapore)).

The species of choice for culture in South East Asia is *Panulirus ornatus* (Figure 1.3.2. 1), with the species found distributed across the Indo-West Pacific region, including Australia. *Panulirus homarus* (also native to Australia) is a secondary farmed species that is increasingly being utilised due to shortages in the availability of *P. ornatus* seedstock (Andrew Jeffs, pers. comm.). The ability to take this industry to a global scale will be dependent on the reliable completion of the hatchery phase of culture, a challenge that until recently was unattainable (Smith, 2017).

Research and development (R&D)

Spiny lobster propagation research has been conducted around the world for more than 50 years, with research focused in the USA, Cuba, Mexico, Brazil, Japan, Singapore, India, Vietnam, Thailand, United Kingdom, Spain, New Zealand and Australia (Phillips et al. 2013). Propagation research on tropical spiny lobsters has been undertaken in Australia since the early 2000's, initially under the umbrella of a FRDC Rock Lobster Enhancement and Aquaculture sub-program, comprising an industry group (Lobster Harvest - MG Kallis Group), Queensland Department of Agriculture and Fisheries, the Australian Institute of Marine Sciences, and the University of Tasmania. This program was discontinued in 2010. Currently, the only spiny lobster research being undertaken in Australia, and one of the few research programs in the world, is being conducted at the University of Tasmania's Institute for Marine and Antarctic Studies (IMAS) (Smith, 2017). In the past 20 years in excess of $40 M has been invested at IMAS into closing the life-cycle of spiny lobsters on a commercial scale (Greg Smith, pers. comm.).

Figure 1.3.2. 1 Adult tropical spiny lobster, *Panulirus ornatus*. (Photo source: Ornatas)

In 2013 tropical spiny lobster research was imbedded into an ARC Industrial Transformation Research Hub, with the primary focus of delivering commercially relevant outcomes for industry. For many years the bottleneck to the establishment of a sustainable spiny lobster industry in Australia, and the world, has been the inability to successfully complete the protracted, complex larval cycle. Recent breakthroughs in technology have resolved the major impediments to sustainable larval production and the reliable supply of *P. ornatus* tropical spiny lobster seedstock (Smith, 2017). Commercialising the outcomes from this research is now a high priority with the construction of the world's first commercial spiny lobster hatchery due to commence in Tasmania by early 2020 with a 12 month build, and production commencing shortly after. Funding for a second 5-year ARC Hub, 'ARC Research Hub for Sustainable Onshore Lobster Aquaculture', was announced in August 2019 (IMAS, 2019), with $5M investment from the ARC and $5M cash and $6M in-kind from the industry partners Ornatas Pty Ltd and PFG Group Pty Ltd.

Potential for northern Australia
<u>Hatchery production</u>
The availability of hatchery-produced seedstock will be a game changer for lobster aquaculture production, both in the established growout sector in South East Asia, through the provision of sustainably produced seedstock, as well as the provision of seedstock for Australian producers. It is envisaged that growout of *P. ornatus* spiny lobsters will be focused in Northern Australia, where there is access to suitable environmental conditions. The development of a high-value spiny lobster aquaculture industry has the potential to provide new opportunities in rural Australia, employment and wealth creation in these communities, high-value seafood security, reduced demand on exploited fisheries, and position Australia as the world leader in spiny lobster aquaculture production. Australia is ideally placed to seize this global opportunity.

<u>Wild seedstock collection</u>
While there may be some opportunity to collect seedstock in Northern Australia the advent of hatchery production will circumvent the need for the removal of animals from the wild to initiate a grow out industry for tropical spiny lobsters. It is likely that lobster seedstock will be supplied either as puerulus (clear nektonic phase) that will require a nursery production phase, or as juveniles (settled phase) where they can be grown out to a marketable size (>700g). Each of these sectors can support viable businesses, although

in some cases, operators may be involved in one or all of these sectors at once (Jones, 2018; Greg Smith, pers. comm.).

Fishing for the seed lobster puerulus involves low technology and basic fishing / marine skills. Artificial habitats are fabricated and deployed into the sea along the coastline in areas likely to support high abundance. The materials and designs are well known from the successful fisheries in Vietnam and Indonesia. Arrays of artificial habitat are suspended from floating frames. Lobster seed settle onto the artificial habitat at night and are retrieved each morning by lifting the habitat arrays to the surface. Internationally, seed are sold to local nursery farmers or exported to Vietnam, where demand exceeds supply. *P. ornatus* seed are currently sold for more than $A5 each. Obtaining permits to collect commercially viable numbers of puerulus from the wild are a potential constraint to a wild-capture based tropical spiny lobster aquaculture venture.

In the past, the lack of knowledge on the availability of naturally settling seed in northern Australia has been an impediment to the establishment of a local lobster aquaculture sector (Jones*, et al.*, 2010). However, with the possibility of hatchery produced seedstock being available in Australia within the next two years (Ornatas developing a commercial hatchery in Tasmania) new culture opportunities will exist.

Nursery production

Nursery farming involves the nurturing of the seed lobsters until they reach 3 to 10 g each. Typically, in Vietnam this would be performed in small (1m diameter) cages that are suspended to a depth of 5m in coastal waters with depth of >10m. Multiple nursery cages are suspended from a moored floating frame. Daily management of the nursery operations is required comprising morning checks of each cage (lifted to the surface), cleaning and feeding. The production cycle is typically 6 to 12 weeks to grow seed to an advanced juvenile stage. Access to suitable marine waters may be a constraint when considering this form of nursery culture in Australia. In the short-term it is more likely that onshore recirculation aquaculture nursery systems would be established in northern Australia, allowing operators greater control over the culture of the seedstock animals. There will need to be significant research effort into optimising onshore culture systems for tropical lobsters that minimise cannibalism while maximising growth and economic benefits.

Growout

The growout of juvenile lobsters to a marketable live product is more intensive, and requires greater capital investment. In Vietnam, floating frames are used to house suspended cages, typically 4m x 4m x 5m deep. Juvenile lobsters are stocked to the cages. In current Asian operations, these are managed on a daily basis, typically by farm staff stationed on the floating frame, i.e. 24/7 operations to ensure effective operation and security given the high value of individual lobsters. Consequently, the floating frame is a substantial structure with basic dwelling and facilities to support staff, generally on a short-term rotational basis, e.g. 2-3 days on farm, 2-3 days off. Growout of *P. ornatus* lobsters typically involves a 20-month cycle from juvenile to 1kg lobster (Jones, 2018).

When considering the various options to growout spiny lobster juveniles to a marketable size the current option that is proven and already exists is seacage culture. This activity has been undertaken in Vietnam for more than 20 years. Whether this is an option in Australia is to be determined with areas suitable for nursing and growout farms need to be identified that meet a series of biological and environmental criteria. Most important will be protection from strong wind / wave action, as the infrastructure is surface-based and only viable with reasonable protection. Suitable locations must have oceanic quality water with marine salinity and very low turbidity, a depth of 10 to 40m. Consideration must also be given to protection from large predators (fish, sharks and crocodiles).

As with juvenile nursery production this form of culture has a number of challenges associated with it in Australia, particularly on the east coast of Australia, they include regulatory issues associated with the Great Barrier Reef Marine Park, access to suitable infrastructure and staffing in remote locations. It is more likely that opportunities to undertake seacage culture of tropical lobsters may exist in the Torres Straits region of northern Australia, particularly if there was support for this activity from coastal Indigenous communities (Kenway et al, 2009). Similarly, in other remote regions of Australia, biological (predator exclusion), physical (strong tidal flows, cyclones), geographical (remoteness, infrastructure and feed costs) and environmental (perceived impacts of seacage culture) considerations will ultimately determine the feasibility of seacage operations in these regions (Kenway et al 2009).

Based on the characteristics of areas with high abundance of seed lobsters in Vietnam and Indonesia, areas likely to be suitable for seed settlement in northern Australia can be identified via mapping and surface assessment. Anecdotal information suggests areas with these attributes are available in sites along the tropical coastline of Australia. For example, Groote Eylandt has previously been identified as a potential site for lobster farming. The establishment of marine farming operations will require new technologies and practices that would be unfamiliar to local people. Consequently, training and instruction will be an integral part of developing lobster farming.

The alternative strategy that is being mooted by the company developing hatchery production for *P. ornatus* is the development of onshore culture systems that will allow high-density culture in environmentally controlled systems (Scott Parkinson, pers. comm.), which is the focus of the second ARC Hub funding announced in August 2019. If onshore lobster aquaculture was to be developed there may be a number of synergies with other existing aquaculture industries, including prawn aquaculture.

Liaison with state and federal government agencies will be necessary to clarify the permits that will be required to collect seed and/or to farm lobster. At this point, these are not expected to be difficult to obtain.

Market

Lobsters are an iconic seafood product in Australia that dominates the crustacean fishery statistics, with an estimated total value for the Australian lobster fishery of approximately $800 million per annum (ABARES 2019). The majority of this fishery product is exported to meet the insatiable global demand for high-value seafood, especially in Asia. Lobsters delivered into these markets sell for in excess of AU$80/kg, especially when shipped live. Consequently, Australia has excellent existing market knowledge, networks, and infrastructure for trading lobsters and a consistently high standard of fisheries management that has resulted in being recognised globally as the pre-eminent supplier of high quality, sustainably sourced lobsters. For example, Australia initiated and hosted the first world lobster scientific gathering in Perth in 1977, which has continued as the largest global gathering of lobster scientists, managers and industry personnel every three years. The application of this scientific capability in Australia has resulted in world-leading technology for the mass culture of hatchery lobster seedstock that can provide a foundation for the emergence of sustainable lobster aquaculture production. There are a number of other *Panulirus* species that naturally occur in northern Australia, and a number of these may also be amenable to culture.

1.3.3. **Crustaceans – Slipper Lobster *Thenus* species**

Species biology

Slipper (or Bay) lobsters of the genus *Thenus* are a common and valuable bycatch of the shrimp trawl fisheries of northern Australia. Until recently there was thought to be a single species of this genus, but two species are now recognised from Australia, *Thenus australiensis* (reef bug) and *T. parindicus* (mud bug), both are commonly known as Moreton Bay bugs (Burton and Davie, 2007) (Figure 1.3.3. 1). There are also a number of additional species that have been described from other regions (Burton and Davie, 2007).

Research into the biology of the species during the 1980s and 1990s, generated important information for fisheries management, and revealed the specialized nature of these lobsters (Jones, 2007). *Thenus* spp. inhabit the soft, sedimentary mud and sand of the continental shelf, particularly in inter-reef areas along the tropical coastline of Australia. Their morphology and behaviour share much in common with other Scyllarids, but also have unique features which reflect successful adaptation to their environment. Most notable are the ability to swim, often long distances, and the capacity to bury into the sediment.

For Queensland, a maximum fishery catch of 755 tonnes was recorded in 1997, and over recent years, the annual catch has been around 400 tonnes. *Thenus* is now recognised as a high value seafood, fetching prices of $25 to $50 per kg for whole lobsters. There is no scope for increased fishery yield, so aquaculture is the only option for increasing production.

Figure 1.3.3. 1 Adult slipper lobster, *Thenus* sp. (Photo source: Ornatas)

Potential for northern Australia

To date, the aquaculture potential of slipper lobsters (*Thenus australiensis*) has received scant attention in lieu of the much stronger interest in the aquaculture of tropical spiny lobsters (*Panulirus ornatus*). This is in part due to the higher market price and international profile of spiny lobsters. Early attempts to culture slipper lobsters were conducted at the Bribie Island Research Centre in Queensland during the 1990s (Mikami 2005), with commercial outcomes currently being tested in a purpose-built facility for *Thenus* in northern NSW. Production in this facility is targeted at producing a small soft-shell product, although due to commercial confidentiality, its success is not clear (Anon., 2016).

Despite attempts to culture slipper lobsters in Australia for more than 25 years, thus far a commercial sector has not been developed that is accessible to new industry players. To address this shortfall in current knowledge researchers at IMAS have applied best practice learnings from spiny lobster larval culture to develop alternate commercial slipper lobster production technology. Through the application of known techniques it is hoped that there will be a fast track to the development of similar commercial protocols for slipper lobsters (Greg Smith, pers. comm.). It is likely the establishment of a commercial hatchery to produce slipper lobsters will occur within the next 2-5 years in north Queensland and provide the impetus to kick start a new industry.

There are a number of advantages that slipper lobsters have over tropical spiny lobsters; they have a shorter larval cycle (3 weeks vs 4 months), reduced growout period (9 vs 20 months) and are less cannibalistic as juveniles. It is highly likely that there will be an increased commercial focus on this species in the short-term. Pilot studies on the culture potential of slipper lobsters are currently in progress under the umbrella of the ARC Research Hub for the Commercial Development of Rock Lobster Culture Systems at IMAS. Testing the growout potential of this species in northern Australia will be important to the development of a slipper lobster aquaculture industry. IMAS and their commercial partner Ornatas are currently investigating a number of options for the growout of slipper lobsters in onshore facilities, initially high-density trials will be conducted in raceway systems. Ornatas will consider a number of commercial growout options for slipper lobsters in northern Australia (Scott Parkinson, pers. comm.). It is likely that the best mix of options are likely to include pond culture, and this will require a concerted financial and research effort within the next 1-3 years.

1.3.4. Crustaceans - Mud crab (*Scylla serrata*)

Species biology/culture characteristics

Mud crabs of the genus *Scylla* have a broad Indo-Pacific distribution, ranging from eastern and southern Africa, southeast and eastern Asia, and northern Australia. Only two of the four mud crab species, i.e. *S. serrata* (Figure 1.3.4. 1A) and *S. olivacea,* are found in Australia; and *Scylla serrata* is by far the most broadly distributed and dominant species caught (> 99% commercial catch in NT, QLD and 100% in NSW), ranging along the northern coastline from Broome in WA, to Bermagui, southern NSW (Keenan et al. 1998, Grubert et al. 2018). *Scylla serrata* primarily inhabits tropical to warm temperate estuaries and sheltered coasts; the species is often associated with mangroves and favours soft muddy bottoms where they can dig and burrow. As an omnivorous scavenger and being nocturnally active, *S. serrata* feeds mainly on molluscs, crustaceans, polychaetes and detritus. *Scylla serrata* is euryhaline and well adapted to brackish water with salinity as low as 4 ‰ (Romano et al. 2014).

Scylla serrata grows relatively fast and can reach sexual maturity in one year at a carapace width of 120–150 mm (Grubert et al. 2018). Courtship and mating occur in estuaries, but mature females migrate offshore to spawn. In the tropics, spawning can occur any time during the year and *S. serra*ta may spawn 2-3 times a year. Each spawn produces between 1 - 6 million eggs, which attach to the female abdomen and are cared for by the female until hatching. Newly hatched larvae develop through five zoeal and a megalopal stages, before they moult and settle as first stage crabs (Figure 1.3.4. 1B), which typically takes 3-4 weeks (Nurdiani and Zeng, 2007; Shelley and Lovatelli, 2011).

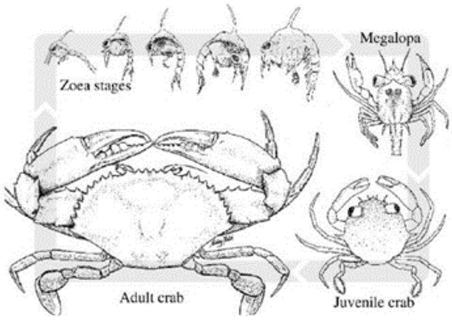
A.  B. 

Figure 1.3.4. 1 A. The mud crab *Scylla serrata;* B. The life cycle of *S. serrata*

Largely based on the stocking of wild-caught crablets, mud crabs have been farmed in China for more than 100 years, and in several other Asian countries for ~30 years. Mud crab farming is currently a sizable industry in these countries, with annual production from China alone exceeding 100,000 tons. Farming of mud crabs in Asia is practiced in both earthen ponds and mangrove enclosures; and in various forms of monoculture, polyculture (with fish, tiger prawn and mangrove silviculture), fattening and soft-shell crab production. The main constraint restricting further expansion of the industry is supply of crablets, since even at the current farming scale in Asia, the quantity of wild-caught crablets is insufficient to meet demand. Hatchery production has been attempted in various countries and successful production of more than a million crablets have been reported in several occasions. However, hatchery larval survival is highly inconsistent and mostly very low.

History of production

In Australia, legislation prevents collecting wild mud crab seeds for aquaculture. Consequently, growout of *S. serrata* has only been trialled on several occasions during the late 1990's and 2000's in NT and QLD with hatchery produced crablets from two major R&D projects funded by ACIAR and FRDC, respectively. All of these growout trials were small-scale and ceased at the closure of projects. As a result, there is no commercial mud crab farm currently operating in Australia.

Research and development (R&D)

ACIAR funded a major R&D project on mud crab aquaculture prior to 2000 (FIS/1992/017) (Keenan and Blackshaw, 1999), which was followed by another project funded by FRDC (No. 2000/210) (Shelley et al. 2008). These two projects were both conducted at the Bribie Island Aquaculture Research Centre and Darwin Aquaculture Centre, with hatchery and nursery phases as the focus. Both projects have substantially advanced knowledge and techniques for mud crab aquaculture, particularly in terms of relevance to the Australian situation. In addition to those projects, small-scale R&D efforts were also carried out by JCU, as well as by industry; for instance, in the early 2000's, a small prawn hatchery in Cairns successfully produced almost a million mud crab crablets, which were marketed to both potential domestic and overseas growout farmers.

There is some commercial interest in the farming of mud crabs in northern Australia; however, developing the industry requires significant investment in R&D. The first and most immediate area of research required is to refine hatchery production technology to produce consistent and high-quality crablets for growout. Once a reliable supply of hatchery produced seed is available, research should then focus on methods to mitigate aggression and cannibalism, along with possible polyculture of mudcrabs with other aquaculture species. Additionally, despite the fact that the mud crab fishery in northern Australia is considered sustainable (Grubert et al. 2018), there is potential for ranching of *S. serrata* by Indigenous communities in mangrove systems as is conducted in many Asian countries.

1.3.5. **Finfish – Grouper (rockcod) *Epinephelus* species and coral trout**

Species biology/culture characteristics

Grouper are reef fish species from the Family Serranidae and Subfamily Epinephelinae, distributed globally throughout the tropics and subtropics. They are carnivorous, feeding on small fish, crabs, other crustaceans and cephalopods, sexually maturing first as females and changing to males later in life. They are a high-value marine finfish, reported to average USD$4/kg but the price is variable depending on species and markets targeted (Rimmer and Glamuzina, 2019). This value has placed pressure on wild fisheries, particularly to supply live reef fish markets in Hong Kong, Taiwan, Singapore, Malaysia and southern China. In an effort to alleviate pressure on wild stocks, aquaculture of grouper species has developed rapidly in the Asia-Pacific since the 1990s (Sugama et al, 2012). In 2015, international production was 155,000 tonnes valued at USD 630 million (Rimmer and Glamuzina, 2019).

Several grouper species are cultured in China and south East Asia. In China, recent production was reported as 108,000 tonnes (Ma and Zhu, 2018). Globally, there are at least 47 species and 15 hybrids that have been investigated as new species or are currently cultured in aquaculture (Rimmer and Glamuzina, 2019). There are concerns about the sustainability of production of grouper species, namely: the use of wild-caught juveniles for some culture systems; growout diets which often consist of 'trash fish' that pose a biosecurity risk and are an inefficient feed; high and variable growout mortality due to disease outbreaks; and poor management of production systems resulting in degradation of water quality and the substrate below farms (Rimmer and Glamuzina, 2019).

Australia has focussed R&D on sustainable intensive hatchery production of high-quality grouper juveniles, in combination with growout in ponds, pens in a saline lake, and recirculating aquaculture systems (RAS), all using formulated compound diets. In the marketplace, grouper are known as "rockcod" in Australia. Groupers are distributed in northern Australian waters from Broome, Western Australia to southern Queensland, with several species investigated (Table 1.3.5. 1).

Figure 1.3.5. 1 Distribution of wild *Epinephelus lanceolatus* in Australian waters, and Asia-Pacific. Range of colours (red – orange – yellow) indicates habitat suitability, with dark red the most suitable habitat. (Source: AquaMaps)

Table 1.3.5. 1 Grouper species that have been investigated in Australia.

Species name	Common name(s)	Attributes	Image
Epinephelus fuscoguttatus	Tiger grouper; Brown-marbled grouper; Flowery cod; Flowery rockcod	Fast growth rate to market size in ~12 months, hardy to culture, good market price	 Image: GBRMPA from Sugama et al, 2012
Epinephelus lanceolatus	Giant grouper; Queensland Groper	Fast growth rate; good market price; high quality flesh	 Image: The Company One
Epinephelus coioides	Gold spot grouper; Goldspotted rockcod	Most commonly cultured and traded species in Southeast Asia.	 Image: Sugama et al, 2012
Plectropomus leopardus	Coral trout; Common coral trout	High quality flesh; Still in R&D to increase survival rates	 Image: The Company One

History of production

Grouper aquaculture research in Australia has been led by Queensland DAF, with most activity based at the Cairns Northern Fisheries Centre (NFC) marine fish hatchery. From the late 1990s, R&D addressed challenging hatchery technologies, including development of reliable copepod production as a live feed for first feeding larvae, and increasing larval survival with proprietary larviculture techniques. In 2015, this hatchery was leased to Finfish Enterprise, and in 2017 the company was purchased by The Company One. The Company One is currently the only supplier of grouper fingerlings for commercial growout in Australia, with an emphasis on giant grouper. Fish are currently supplied to Rocky Point Aquaculture (in southern Queensland) and to Truloff Farm Prawns (Cardwell Farm) to test giant grouper as a potential species for diversification of farming in prawn ponds. Fingerlings are also supplied for growout to RAS operations in Australia (Ecomarine, Noosa QLD) and Hong Kong (Aquaculture Technology Asia) as well as pond growout in Taiwan.

It takes approximately 40 days from hatching for giant grouper to be weaned from live feeds to formulated diets and for metamorphosis to fingerlings, after which they are transferred to the nursery. In a further 2-4 weeks, they are ready for transport to growout systems. Time to harvest size, ~800 g, is dependent upon rearing temperature and conditions, but is typically less than 12 months.

The research to investigate alternative fish species for pond culture was prioritised after the white spot syndrome disease (WSSD) outbreak in southern Queensland in 2017. In conjunction with supporting the prawn industry with R&D to avoid future WSSD outbreaks, there is an ongoing need to de-risk the investment of aquaculture companies by providing alternative species ready for production in prawn ponds. Groupers are seen as a group of fish species that could be farmed in prawn ponds without significant modification of pond infrastructure.

Research and development (R&D)

There have been two large ACIAR projects involving grouper aquaculture, funding research activity in the Cairns NFC hatchery and internationally (ACIAR project FIS/2002/077 (Sugama et al, 2012); and FIS/97/73 (Rimmer et al, 2004)) (

Table 1.3.5. 2). In terms of adoption of grouper as an alternative species for prawn culture there are two current FRDC projects (FRDC 2017-103; 2018-157). The most recent project has developed a vaccine for nodavirus and is exploring product formats for market. The results in terms of improved fish health, production and market opportunities are pending.

Table 1.3.5. 2 Research funding for grouper aquaculture in Australia.

Project Title	Agency and Project No.
Improved hatchery and grow-out technology for grouper aquaculture in the Asia-Pacific region	ACIAR FIS/97/73
Improved hatchery and growout technology for marine finfish aquaculture in the Asia–Pacific region	ACIAR FIS/2002/077
The evaluation of two species, Cobia and Giant Grouper, as alternative species to farm in the WSSV affected areas of South East Queensland	FRDC 2017-103
Evaluation of Cobia and Giant Grouper production and health in multiple growout systems, as an alternative species to farm in WSSV affected areas of South East Queensland	FRDC 2018-157

There are several areas of potential R&D for grouper aquaculture in northern Australia:

- Market and value-added product development in giant grouper (e.g. live, processed whole, processed whole and packaged, processed (portions) and packaged), in domestic markets and for export, particularly important if the scale of production increases in Australia to avoid a price decrease.
- Optimum land-based production systems for grouper (pond and recirculating aquaculture systems (RAS)).
- Diagnostics, surveillance and development of health management plans for challenges to grouper health in different growout systems.
- Improved hatchery efficiency of giant grouper and other grouper, *Epinephelus,* species to diversify species available for growout and mitigate potential market fluctuation.
- Selective breeding of grouper to increase growth and disease tolerance.

1.3.6. **Finfish – Cobia *Rachycentron canadum***

Species biology/culture characteristics

Cobia (*Rachycentron canadum*) is a large benthopelagic, migratory and carnivorous species with a widespread tropical and subtropical distribution across the globe, except for the eastern Pacific (Shaffer & Nakamura 1989). Cobia are primarily solitary in the wild, a behaviour that does not support commercial fisheries, and catches are mostly incidental and from recreational fisheries. Perhaps for these reasons the fish is not widely available in the market and is largely unknown to the general public. Global production is reported to be 80,000 tonnes annually: 40,000 tonnes from capture fisheries and 40,000 tonnes from aquaculture (FAO, 2019). Cobia is an euryhaline and eurythermal species, tolerating brackish water cultures as low as 10 ppt and temperatures from 20 to 33 ^{o}C, with optimum growth around 29 ^{o}C. Cobia is a gonochoristic species (born either male or female) with sexually dimorphic growth rates whereby females grow around 30% faster than males, although their exact sex determination system is unknown and technology for all-female stocks does not currently exist.

The main farming attributes of the species are their impressive growth rates of 7-8 kg (market size) in just 18 months, high quality and firm texture white meat, and relative ease of propagation and culture in captivity. Broodstock husbandry and larviculture management of cobia are similar to other tropical marine species like barramundi (i.e. spawning of sexually mature fish can be induced via hormonal induction and large larvae can be fed enriched rotifers at first-feeding). Low technology greenwater larviculture techniques followed by extensive open pond culture after 10 days post-hatch are traditionally used in Asia and, until recently, in Australia (Palmer et al., *in press*, Lee et al., 2015). The use of indoor, intensive tank-based hatchery culture has been developed in the USA (Benetti, 2008). In Australia this innovation has been adopted to address the lack of biosecurity and unpredictability of seed production of open systems. Survival rates in the initial stages (from larvae to juveniles) are still 30% or below.

Cobia is cultured in coastal seacages throughout south east Asia where China, Taiwan and Vietnam are the main producers (Nhu et al., 2011). Initiatives have begun in the Americas, including Brazil (Sampaio et al., 2011) and the Caribbean where cobia is farmed in offshore submersible cages (Benetti et al., 2010). High-energy environments more easily sustain farming of pelagic species like cobia with high growth rates supported by high feed consumption (and excretion), high oxygen demand and high carbon dioxide release. In pond culture systems, excess nutrient loadings are often managed with aeration and high water exchange. Cobia lacks a swim bladder and must swim to maintain buoyancy. When not swimming, they are often found resting at the bottom, particularly at night. For these reasons, pond culture is more problematic than sea cage culture, as water quality issues and increasing excretions as the fish grow, increases the risk of pathogen and disease outbreaks.

History of production

In Queensland, due to regulatory and climatic issues with sea cage farming, mariculture investments have been directed at prawn and barramundi farms in earthen ponds. Earthen ponds as a farming system has been utilised by prawn and barramundi farms due to regulatory and climatic issues with sea cage farming (Palmer et al., *in press*). Following approaches from several established aquaculture operators in 2006, the Bribie Island Research Centre (BIRC) supported a cobia R&D program to evaluate the technical feasibility of cobia farming in Queensland. BIRC investigated the technical requirements to breed and produce juveniles for grow out trials in pond systems (Palmer et al., *in press*). Despite the unfavourable shallow pond environment, low temperatures in winter and lack of a specific diet at the time, the initial results were positive from a technical perspective. Harvest weights of 2-3 kg were achieved in southern QLD (Logan) and 4-6 kg in northern QLD (Ayr) after about 60 weeks from stocking, while FCRs of 2.1 to 2.5 and survival of 65 - 90% were recorded (Palmer et al., *in press*).

While the project did not evaluate the feasibility of cobia farming from an economic perspective, it is likely that higher profitability of shrimp farming would not justify the conversion from shrimp to cobia. From the few participant farms that partook in the initial project, only Pacific Reef Fisheries Ltd. (PRF or now Pacific Bio) has continued the R&D partnership with BIRC to develop an Australian cobia aquaculture industry. Supported by funds from the QLD government, the former Australian Seafood CRC and the FRDC, the farm is producing around 100 tonnes of cobia per year (Lee et al., 2015, 2018). Since the white spot virus outbreak in the Logan area in 2017, Rocky Point Aquaculture has ceased shrimp operations and, with support from the FRDC, has begun to evaluate the feasibility of cobia farming in floating cages within an artificial seawater lake within the property. Rocky Point has recently converted its former shrimp hatchery into a fish hatchery and nursery, with the goal to overwinter juveniles in heated recirculation aquaculture systems (RAS) to stock juveniles in late spring when outdoor temperatures are more favourable for cobia grow out.

Market

In Australia, cooked fresh cobia has been rated equivalent to Atlantic salmon and superior to yellowtail kingfish in terms of overall appeal, flavour and texture by an expert consumer taste panel (Lee et al., 2015). Current produce available in Australia are sold at high-end restaurants and catering, and the product has won multiple awards (Courtney, 2016). However, the balance between supply and demand is a key consideration for a product still largely unknown to consumers should larger volumes of cobia become available in the market. Internationally, a rapid increase in aquaculture production in China resulted in a sharp decline in cobia prices from USD $6.66 per kg in 2000, to less than USD $1 in 2009 (Freeman et al., 2010).

Research and development

In the last decade, R&D efforts have addressed the controlled reproductive development of captive cobia for the production of seedstock through both greenwater and indoor tank-based larval culture systems. In addition, a pond-based system capable of producing 20 tonnes per ha has been developed, at least at a limited scale. It is unlikely that this production model utilizing shallow earthen ponds designed for shrimp farming would be scalable to larger production areas than that currently utilized by Pacific Bio, given high nutrient loading and water quality management issues. Significant barriers to industry uptake and development still exist, including reliance on a single government-operated hatchery and limitations to growout opportunities restricted by available pond space, at least in QLD (Dutney et al., 2017). Importantly, cobia cage culture in the NT and/or WA has not yet been evaluated.

Several key research objectives remain to further develop the industry in northern Australia. Under the current pond-based model of production, research is required in the evaluation of growout performance in deeper plastic-lined ponds designed for the species; cost-effective effluent treatment and water re-use strategies; use of recirculation aquaculture systems for indoor nurseries; development of cobia feeds for sub-adults (>2 kg) tailored to minimise waste production and/or facilitate waste collection; development of cobia strains more amenable to pond-based culture; and the epidemiology of common diseases and adequate disease treatments.

1.3.7. Finfish – other freshwater and marine species (freshwater - silver perch, jade perch, Murray cod, eel-tailed catfish, sleepy cod, barramundi cod, and silver cobbler; marine – snubnose pompano)

Species biology/culture characteristics

There are several native species of freshwater fish produced for aquaculture in northern Australia. They have different characteristics suited for culture, with information on silver perch and Murray cod readily available.

History of production

In Queensland, current freshwater fish production includes silver perch (*Bidyanus bidyanus*), jade perch (*Scortum barcoo*), Murray cod (*Maccullochella peelii peelii*) and eel-tailed catfish (*Tandanus tandanus*). In 2017-18, total production of these species was 231.7 tonnes, with a value of $2.9 million (DAF 2018b). Silver perch accounted for 96 tonnes, $1,032,224, with an average price of $10.81/kg. Feed conversion ratio for silver perch was 1.9:1 in 2017-18. Jade perch production was 117 tonnes, worth $1,462,360, with an average price of $12.49/kg. Client confidentiality prevents disclosure of Murray cod and eel-tailed catfish production which occurs in southern QLD.

Research and development (R&D)

Murray cod has potential for aquaculture in the Atherton Tablelands of QLD, although other areas in northern Australia would be restrictive due to high water temperatures. The Murray Cod industry is expanding rapidly in NSW and Victoria driven by high market demand and price for whole live or fresh product in markets in Melbourne and Sydney. There is potential for a large export market, with a premium price anticipated for live fish, although high production volumes are likely required for entry to some markets (e.g. China).

Others tropical species, such as sooty grunter (“honey perch”) *Hephaestus* sp., jungle perch *Kuhlia rupestris*, and sleepy cod *Oxyeleotris lineolata* have been considered for production in northern Australia, although more R&D into commercial scale culture of these species would be required.

Other identified opportunities for new freshwater species for aquaculture, include silver cobbler *Neoarius midgleyi*. The species is locally known in northern Australia. Anecdotal information, particularly linked to barramundi farming trials in Lake Argyle in the 1980s, indicates that it is fast-growing, suitable for freshwater aquaculture, and there are available technologies for catfish (e.g. *Pangasius* sp. and *Clarias* sp.) that could be adapted for development. Silver cobbler is identified by CSIRO as one of the strategic species for future aquaculture development in Western Australia and northern Australia (Hoang Tung, pers. comm.).

The snubnose dart (internationally, known as snubnose pompano) *Trachinotus blochii* has also been identified by CSIRO as a species with potential for marine and brackish water aquaculture in northern Australia (Hoang Tung, pers. comm.). While it is not well-known in domestic markets, pompano is a highly regarded fish, in demand in Asia, and commands good market prices. The species is widely distributed in northern Australia, spawning year around, and is fast-growing. In Asian live fish markets, it is sold at both plate size (600 – 800 g) and for fillet (2.0 – 2.5 kg). Hatchery and farming technologies are established and available for transfer to an Australian context. Pompano can be farmed in coastal ponds with salinities as low as 9 ppt (Pathak et al. 2019). Significant improvement of production efficiency could be expected with research. Integrated farming with prawns could also be considered in Australia.

1.3.8. **Molluscs – Black-lip rock oyster, *Saccostrea echinata***

Species biology/culture characteristics

The black-lip rock oyster *Saccostrea echinata* is a large, dioecious, adherent oyster species with a fast growth rate. In an intertidal farming system, the species can grow to a market size of 70 mm within two years (Samantha Nowland, pers. comm. 2018) and in the wild oysters frequently grow to 180 mm in length (Thomson 1953). The black-lip rock oyster is broadly distributed throughout the tropical Indo-Pacific and a recent genetic study also confirmed the species presence across northern Australia, from Bowen (Queensland) to Cone Bay (Western Australia) (Nowland et al. in press). A comprehensive assessment of *S. echinata*'s distribution in Australia, however, is yet to be completed and understanding its range is likely to be complicated by high levels of morphological variability, the presence of few distinguishing characteristics and also several morphologically similar co-occurring oyster species that are yet to be delineated and described. Current research using molecular tools is being undertaken to investigate species boundaries and distributions of rock oysters in Queensland (Dr C. McDougall, Griffith University) and Western Australia (Drs L. Kirkendale, N. Wilson Western Australian Museum).

S. echinata is not known to be an abundant oyster within its range (Glude 1984), and unlike its southern counterpart, the Sydney rock oyster (*Saccostrea glomerata*), it does not naturally occur in large aggregations, but rather, as isolated individuals at the low tide level on rocks and mangrove roots (Thomson 1953).

Very little is known about the reproductive biology of the black-lip rock oyster, although recent research has shown (in Northern Territory populations) that the species spawns semi-continuously throughout the monsoon season (October-April), with an extended resting phase evident in the dry season (May- September) (Nowland et al. 2019b). The gonad index of the black-lip rock oyster was also shown to be strongly correlated with temperature and moderately correlated with rainfall, suggesting the species spawns after high levels of monsoonal rainfall.

Oyster production

Global production of edible oysters is approximately 5.3 million tonnes, with over 97% produced from aquaculture (Australian Venture Consultants 2016). Over 80% of global oyster production comes from China. Australian edible oysters command a very high price; in 2014 Australia produced around 0.2 % of global edible oyster production by volume but 2.2% by value (Australian Venture Consultants 2016). In 2016-2017 the Australian oyster industry was worth \$112 million, comprising ~\$44 million from Sydney Rock oysters and ~\$68 million from Pacific oysters.

For *S. echinata,* specifically, several small farms have existed across the Pacific region since the 1970s, however none are currently culturing commercial product (Coeroli et al. 1984). Difficulties in farming the species, including low numbers of wild spat recruitment, lack of hatchery production, and limited funding (see Nowland (2019) and references within) made the industrial-scale culture of the species uneconomic. Despite difficulties in establishing commercially viable operations, several small-scale experimental farms currently exist in indigenous communities in the Northern Territory and a commercial farm in Bowen (Queensland).

There is renewed interest in farming the oyster (see below) and current efforts are underway in the hope of expanding the industry across northern Australia.

Research and development (R&D)

Reliable spat supply is a well-recognised bottleneck for commercial production of black-lip rock oysters. Therefore, reliable hatchery production will be crucial to further development of the industry. The Northern Territory Government believes this species shows particular promise for successful aquaculture ventures in remote Aboriginal communities as the oyster can be grown using limited machinery or technology and is amenable to initial trial cultivation in remote locations.

The NT Government has recently supported research into hatchery culture techniques for *S. echinata* (Nowland et al. 2018b; Nowland 2019; Nowland et al. 2019a). In addition to characterising the early life history development of *S. echinata* (Nowland et al. 2018a) this work optimised salinity and water temperatures for embryonic and larval development (Nowland et al. 2019a), as well as stocking densities and microalgal rations for the major development stages (Nowland et al. 2018b). Notable population genetic structure was also detected in wild stocks of *S. echinata* either side of the Wessel Islands (NT), suggesting that these populations should be managed separately.

Comment/perspective on what could be solved with R&D, and industry potential growth

Northern Territory Fisheries held a National Tropical Oyster workshop in October 2018. The workshop was held in recognition of the increasing interest in tropical oyster aquaculture in the Northern Territory, Western Australia, Queensland and northern New South Wales. Representatives from Aboriginal communities, industry, government agencies and researchers were brought together to discuss strategic research and development priorities to develop a tropical oyster industry. This has fostered greater collaboration across various projects and provided a strategic direction to future research and development activities.

Key recommendations from the workshop were:

- Engage early with Aboriginal groups to build collaborative partnerships.
- Undertake targeted research to improve hatchery production of Black-lip Oysters.
- Develop informed, risk-based protocols to manage the translocation (spat and broodstock) and biosecurity risks.
- Address knowledge gaps to implement targeted, risk-based and informed shellfish quality assurance programs, suited to the north Australian environment and remote context.
- Develop production systems suitable for northern Australia.

Table 1.3.8. 1 Government research funding to the Northern Territory for tropical rock oyster aquaculture in Australia.

Funder	Project #	Project title	Date
NAMRA	F20140017	Developing Indigenous Capacity–Marine Based Enterprises	Sep 2013–Dec 2016
TNRM	NTRM00377	Tropical Rock oyster Research and Development: heavy metal management and knowledge exchange pathways	Nov 2015–Jul 2016
TNRM	NTRM00463	Capacity building for Indigenous management of on-country aquaculture development-shellfish quality assurance in the NT	Aug 2016–May 2018
TNRM	TNRM00575	Supporting remote economic development: investigating wild seed supply for tropical rock oyster aquaculture	Nov 2017–May 2018
TNRM	NTRM00318	Tropical Rock Oyster R&D: knowledge exchange pathways and on country capacity building	April 2015–June 2015
NTG	Internal project	Tropical Rock Oyster Aboriginal Economic Development Project 2016–2018	2016–2018
FRDC	2012/223	Assessment of heavy metals in tropical rock oysters (blacklip and milky) and implications for placement into the Australian seafood market and for Indigenous enterprise development in the NT	August 2012–June 2015

The CRC for Developing Northern Australia have recently supported a grant (2019-2022) to further solve bottlenecks to the growth of the industry through research and development. The key focus areas of this CRC project include:

1. Understanding the genetic distribution of tropical rock oysters – this is necessary to inform a risk assessment of rock oyster movement risks and help define oyster growing regions policy for northern Australia
2. Securing consistent spat (juvenile) supply – this includes both evaluation of wild spat collection methods and developing broodstock conditioning and spawning/larval rearing procedures.
3. Optimising gear technology – this includes determining the relative performance of gear technology through field trials.

Additional research and development is necessary in order to determine correct taxonomic identification and establishment of the species range, as well as understanding spawning patterns and synchronisation over the species range, particularly between genetically distinct populations.

As filter feeders, bivalves such as oysters and mussels are well-recognised for their ability to improve water quality and clarify and remove nutrients from the water column. In temperate regions there has been particular interest in the role that cultivated shellfish can play in the removal of excess nitrogen (in particular) from waterways (Ferreira & Bricker 2016). Due to this 'ecosystem service', bivalve culture may be an important player in future nutrient trading schemes. Future developments in this area will likely have a greater focus on temperate regions, however, as large rainfall events in the tropical wet season play a much greater role in flushing nutrient laden water into oceanic waters than in temperate regions. Therefore, the capacity for tropical oysters to make a significant difference to nutrient loads during large rainfall events may be limited. Tropical oysters may have a role to play as 'nutrient scrubbers' in integrated multi-trophic aquaculture however. Initial pilot projects culturing black-lip rock oysters in conjunction with barramundi appear promising, yet more research in this area is required.

Shellfish Quality Assurance

Shellfish quality assurance is particularly important for the development of new oyster aquaculture species, and before oysters can be sold from growing areas within Australia, they must first be classified under the Australian Shellfish Quality Assurance Program (ASQAP) guidelines, which adhere to the Food Standards Australia New Zealand (FSANZ) (ASQAP 2016). ASQAP was developed to provide a consistent approach to undertake quality assurance monitoring in the oyster industry, predominantly in eastern and southern Australia. However, the northern Australian context provides additional challenges of remoteness, distance and environmental characteristics that may not be adequately considered.

A contextual shellfish food safety quality assurance program is required to ensure product quality, as well as the pristine environment and early stage of industry development. As an example, preliminary studies have identified naturally high Cadmium (Cd) levels in wild *S. echinata* that exceeded the 2 mg kg-1 Cd trigger level in the FSANZ (Fleming et al. 2015). However, the process of Cd accumulation in tropical oysters is not well understood and the two proposed mechanisms within the limited literature suggest it relates to phytoplankton blooms, or a process involving dissolved iron and Cd naturally occurring in sea water (McConchie and Lawrance 1991; Munksgaard et al. 2017). Current research supported by the FRDC aims to map the distribution and concentration of Cd in wild *S. echinata* populations across the Northern Territory to better understand the risks associated with Cd and inform the development of a NT Shellfish Quality Assurance Program. However, continued research on shellfish quality assurance and product cold chains will be required to progress the development of *S. echinata* as a viable aquaculture species, within an Australian regulatory context.

Equally important for the development of a new aquaculture species is the economic viability of enterprises. Aligned services and programs are required to address indigenous community business capacities and arrangements including: corporate structures and responsibilities, community ownership and governance structures, land tenure arrangements, understanding of oyster farming requirements, and capacity in shellfish quality assurance sampling techniques and oyster husbandry.

1.3.10. **Molluscs – Abalone (tropical)**

Species biology/culture characteristics

The Donkey ear abalone *Haliotis asinina* is widely distributed throughout the Indo-Pacific (Yu et al., 2014), including tropical reefs located in Queensland, Northern Territory and northwest Western Australia (Freeman, 2001). It differs morphologically from other abalone in that it possesses a greatly reduced and relatively fragile shell accounting for about 6% of the total body mass (Baldwin *et al*., 2007) (the shell of temperate abalone species comprises around 30% of the total body mass).

Haliotis asinina feeds on micro-algae (epiphytic diatoms) during their early life stages, then shifts to a diet of seaweeds (e.g. *Gracilariopsis*) as large juveniles and adults (SEAFDEC Aquaculture Department, 2000). *Haliotis asinina* are small 'cocktail' size abalone that have been recorded to reach a maximum shell length of 120 mm and a body weight of 240-250 g (Bautista-Teruel et al., 2017). They have exceptionally fast growth rates and can grow to a market size (50-60 mm shell length) within 1 year (Hahn, 1989; Freeman 2001) (in comparison, temperate species take approximately 2–3 years (Hahn 1989). *Haliotis asinina* can reach sexual maturity within 12 months while occupying a shell length ranging between 30.5-100 mm (Freeman, 2001). *Haliotis asinina* is also highly fecund; a single spawning estimated between 200,000-600,000 eggs (Singhagraiwan & Doi 1992). Within central Queensland, spawning was shown to extend from October to April and was predictable; being correlated with the time of evening high tides (Freeman, 2001).

There is an established market for *H. asinina*, with the abalone fished in south-east Asia being consumed in that region, as well as in China, Japan, Europe and Australia. Furthermore, abalone have been an important food source for Indigenous Australians for many thousands of years and their shells occur commonly in middens (McNiven & Hitchcock 2004).

Abalone production

The total amount of abalone produced on farms worldwide has increased significantly (50 metric tonnes in 1970s to 162,771 metric tonnes in 2016) (FAO 2019), while abalone fisheries have declined substantially (20,000 metric tonnes in 1970s to 6,500 metric tonnes in 2015) (Cook, 2016). Global wild-caught abalone production fell from 9,229 tonnes to 6,446 tonnes from 2006-2016 as a result of restrictive fisheries quotas and declining wild stocks (Cook 2016, FAO 2019).

Market

Within Australia, 90-95% of abalone are exported to Asian markets (Australian Agribusiness Group, 2006). Currently Australia produces mostly wild-caught (temperate) abalone, but projected growth will come from aquaculture as Australian wild-caught volumes will likely be constrained by conservatively set total allowable catch (ABARES, 2019). A growing demand in China and reduction in tariffs of Australian abalone entering China has led to increasing abalone unit export prices from Australia over recent years (ABARES, 2019).

Historically, the Philippines have been the leading exporter of *H. asinina*, producing an average of 440 tonnes of abalone (USD 2.35 million) annually from 1990 to 2005 (Bautista-Teruel et al., 2016). However, exports have declined severely in recent years (from 633 tonnes in 2004 to 218 tonnes in 2008), most likely as a result of overfishing and habitat degradation (SEAFDEC Aquaculture Department, 2016).

Research and development (R&D)

Culture techniques for *H. asinina* are relatively well-established and have been developed in Thailand, the Philippines and Australia (Hone & Fleming 1998; Freeman, 2001; Tahil & Dy 2015; SEAFDEC Aquaculture Department, 2017), with pilot scale trials undertaken in Queensland and Western Australia (Freeman, 2001).

To obtain optimal growth in culture conditions, *H. asinina* require continuous inflow of sand-filtered seawater, vigorous aeration, a temperature of 28 °C (Hone & Fleming, 1998), pH of 7.99 (Tahil & Dy, 2015), and water salinity ranging between 28 and 32 ppt (SEAFDEC Aquaculture Department, 2017).

Market

Despite culture conditions being well-established, the aquaculture production of *H. asinina* within Australia is non-existent. This is likely to be partially due to the fact that the meat texture from *H. asinina* is generally softer than temperate abalone, likely related to its faster growth rate. This softer flesh texture is less favoured in Asia and, as such, is considered a lower quality product with a corresponding lower wholesale price in the market (Freeman, 2001). Within Australia, the average beach price of temperate abalone (black lip and green lip) increased rapidly from AUS$35/kg in 2004 to AU44.65/kg in 2006 (Australian Agribusiness Group, 2006), with the retail price now around AU$100 per kilogram within Sydney markets (Sydney Fish Markets, 2017). In comparison, *H. asinina* commands prices around US$10-14 (AU$12-17) per kilogram live within Asian markets. In Maluka (Indonesia), the selling price of dry *H. asinina* ranges from IDR 300 000 (AU$28)/kg to IDR 500 000 (AU$47)/kg (Tubalawony *et al.,* 2016). Shells of *H. asinina* have been sold for AU$6.20 per 100g (Etsy, 2017).

The behaviour of *H. asinina* may detract from its suitability as an aquaculture species. It is known to be highly active and capable of prolonged and rapid movement (Baldwin et al. 2007), particularly at night. Farmed temperate abalone are more sedentary, which favours the use of land-based slab tanks for culture in Australia. The behaviour of *H. asinina* is likely less suited to the established Australian farming system.

Comment/perspective on what could be solved with R&D, and industry potential growth in NA

Within Australia, temperate abalone (*H. laevigata* and *H. rubra*) have been shown to rank at the top of the list of species vulnerable to climate change (Pecl *et al.,* 2014; Hobday 2018). Spikes in water temperature (or marine heatwaves) are known to be an important contributing factor in mass mortality events of abalone, known as “summer mortality” (Pearce & Feng 2013; Vandepeer 2006; Travers *et al*., 2009). Marine heatwaves are predicted to increase in the future (Frölicher *et al*., 2018) and, therefore, summer mortality is likely to become an increasingly important issue for farmers of temperate abalone in Australia. Given its broad tropical distribution and higher optimal temperature than temperate abalone species, culture of *H. asinina* may present as an attractive alternative. Opportunities may also exist for integrated multitrophic aquaculture of *H. asinina* in conjunction with established fed tropical aquaculture industries. Integrated aquaculture incorporating abalone is established in China (Fang *et al.*, 2016) and South Africa (Nobre *et al.*, 2010), but has received little attention in Australia. Research could investigate the feasibility of culturing abalone fed on macroalgae grown from prawn or barramundi aquaculture wastewater.

Ocean ranching may also be a possibility for *H. asinina,* particularly given that its highly active behaviour reduces its suitability for land-based slab tanks. 'Ocean Grown Abalone' successfully ranch greenlip abalone (*H. laevigata*) in Flinders Bay, Western Australia on artificial reefs (known as 'abitats'). They seed these abitats with hatchery bred juveniles, and the abalone grow until they reach marketable size 2-3 years later. To our knowledge, this form of farming is yet to be explored for *H. asinina*.

1.3.11. **Molluscs – Tridacnid clams *Tridacna* spp and *Hippopus* spp.**

Species biology/culture characteristics

Giant clams are marine molluscs found extensively throughout Indo-Pacific coral reef systems and which belong to the Family Tridacnidade. This family comprises two genera, *Tridacna* and *Hippopus*, comprising 11 species. The largest of the species is that of *T. gigas* which has been shown to grow to over 135 cm (Ruscoe, 1962).

Giant clams exist in a symbiotic relationship with photosynthetic dinoflagellates (*Symbiodinium* spp), which besides their large size and use as a food resource (e.g *T. gigas*, *T. derasa*), makes them excellent aquarium species due to their hypertrophied and colourful mantle (e.g *T. crocea* and *T. maxima*) (Norton and Jones, 1992) (Figure 1.3.10. 1).

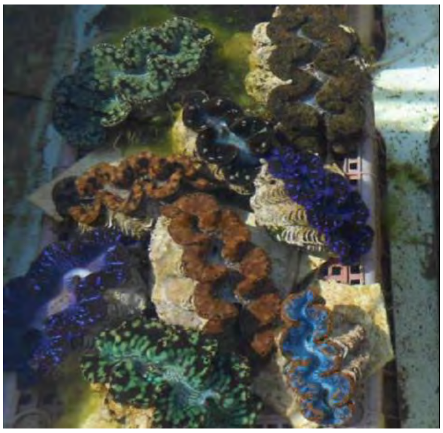


Figure 1.3.10. 1 *Tridacna crocea* and *T. maxima* broodstock highlighting the hypertrophied and colourful mantle. (Source; Mies et al., 2017).

Due to their attractiveness tridacnid clams have been extensively sought leading to over harvesting in many localities. They have been harvested generally for subsistence or as ceremonial food for coastal communities, to supply high-value food markets in Asia, for the international aquarium trade, and more recently, shells for carving in China, as an alternative to ivory (Moorehead, 2018). Consequently, all tridacnid clam species are listed as "vulnerable" in the International Union for Conservation of Nature's *Red List of Threatened Species* (IUCN, 2016; Mies et al., 2017) and their collection from the wild and trade are restricted. However, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) does permit the trade of giant clams produced from aquaculture. A survey conducted by Mie et al., (2017) suggested that most of the aquarium trade is going to Western countries, while Asian and Pacific ocean countries like China and Japan also buy them as food. Wild harvest of the True Giant Clam, *T. gigas,* is illegal as they are a protected species under CITIES, although permits may be obtained for scientific purposes (CITES, 2016).

History of production

Due to the decline in clam populations among Pacific Island communities, aquaculture protocols were developed for several species in the 1980s and 1990s. This work was primarily associated with the aquaculture of clams and what they offered for coastal community livelihoods. Here agencies such as the International Centre for Living Aquatic Resources (ICLARM, now the WorldFish Center), the Micronesian Mariculture Demonstration Center in Palau, and James Cook University, with funding from the Australian Centre for International Agricultural Research closed the life-cycle and developed the appropriate hatchery technologies. However, due to the cost of maintaining a hatchery the development of commercial operations was spasmodic across the region and there are only a few currently active programs (

Table 1.3.10. 1; Moorehead, 2018). In Australia most of this early hatchery and grow out work was conducted at James Cook University's Orpheus Island Research Station (Copland and Lucas, 1988), where still today on the reef flat there are large numbers of aquaculture produced giant clams. Mia et al., (2017) indicate that there is one company selling tridacnid clams from south-western Australia, however, no further information can be found on this company, although a web search has revealed that the company Tycraft Pty Ltd sought a license to collect *T. gigas* from the Cocos (Keeling) Islands in 2015.

CITES data suggests that the countries playing the biggest roles in trade are Vietnam (where there is no aquaculture production, just wild collection of *T. crocea*, *T. maxima* and *T. squamosa* for the aquarium trade), French Polynesia (collection of wild spat and growout) and Palau (aquaculture production of *T. derasa* for both food and aquarium trade) (CITES, 2019). However, the actual value of the trade has not been estimated due to a lack of sales data by country, although it is suspected that around 170,000 clams are available yearly for trade purposes (Mia et al., 2017).

Table 1.3.10. 2 shows the estimated current aquaculture-derived production of giant clams.

Table 1.3.10. 1 Giant clam aquaculture programs in the Pacific region (Source: Moorehead, 2018).

Country	Brief history	Current status
Cook Islands	Hatchery production on Aitutaki since the early 1990s, for restocking/local use and some export for the aquarium trade[1,2]	Active[2]
Federated States of Micronesia (FSM)	Hatcheries in Kosrae (since 1991) and Pohnpei (since 1989), for restocking and commercial purposes (FSM is a significant supplier for the aquarium trade)[1,2]	Active, though production is reported to have declined recently[2]
Fiji	Active programme since the mid-1980s, when hatchery was established on Makogai Island[3]	Active, and currently being revitalised by the government[3]
Kiribati	A private-sector hatchery was set up on Tarawa in 2001 producing for the aquarium trade[4]	Active, but limited production in recent years[2]
Marshall Islands	Long-standing programme, with several hatcheries established; a major supplier to the aquarium trade[2]	Active
Palau	One of the earliest giant clam hatcheries, the Micronesian Mariculture Demonstration Center (now the Palau MDC) has provided aquacultured giant clams to many other countries in the region to help them set up their own programmes; also produces for restocking and for export for the meat and aquarium trade[2]	Active, though production and export are reported to be erratic[2]
The Philippines	One of the longest standing aquaculture programmes, set up by the University of the Philippines in the 1980s under the original ACIAR project. A major restocking programme has supplied many thousands of giant clam juveniles to communities and resorts[3]	Active, producing juveniles, training in handling and management, and carrying out research[3]
	A private-sector hatchery was set up by Semirara Mining and Power Corporation in 2010 as part of its corporate social responsibility programme[3]	Active, producing several species for a marine sanctuary[3]
Samoa	Programmes on and off since the 1980s; current hatchery opened in 2014[3]	Active, with approximately 45 villages involved in grow-out, for their own use and conservation[3]
Solomon Islands	A key country in the early giant clam projects, and a focal point for giant clam aquaculture research in the region, the programme was derailed by civil tensions in 1999 (it briefly recovered from 2005 to 2010 but when donor funding ceased the government was unable to continue activities)[5]	Not active[5]
Tonga	Programme established in the late 1990s for restocking and export for aquarium trade[2]	Active, but erratic production and declining exports in recent years[2]
Vanuatu	Hatchery set up in the early 2000s for restocking and supplying the aquarium trade; in 2005 a commercial operation took over production[1]	Active, but production has declined in recent years[2]

Research and Development (R&D)

The hatchery production of giant clams is generally considered to be known, although obvious refinements increasing the survival of seed stock would be an advantage (Phillip Dor, pers. comm.). Mia et al., (2017) suggests that survival from fertilised eggs through to settlement of juvenile clams is only 0.1%, so despite the fact that clams are highly fecund producing millions of eggs during a single spawning, research into increasing survival rate could dramatically increase supply of farmed grow out animals. In general, it seems that some of the main technical issues actually do not relate to the biology of the animal, but more so to access to high-quality broodstock given that large broodstock are generally rare and protected from collection. Mia et al., (2017) also suggests that attention could be devoted into addressing the clams' slow growth rates comparative to other bivalves (possibly through genetic selection), better spawning induction methodologies, and parasite control. However, it seems that the major issue for the industry to develop and where there may be a strategic advantage here for northern Australia is related to infrastructure requirements and remoteness of production which have plagued the industry given that it has largely been associated with Pacific island nations. A large part of the market for clams is situated in the USA and Europe and thus the transport of clams becomes logistically more challenging and, in some cases, cost prohibitive.

Table 1.3.10. 2 Reported production for seven aquaculture species of giant clams by countries with known farms operating in the Indo Pacific region. (Source; Mia et al., 2017).

Country	*Tridacna crocea*	*T. maxima*	*T. squamosa*	*T. derasa*	*T. gigas*	*Hippopus hippopus*	*H. porcellanus*	Total	Relative contribution
Hatcheries									
Australia[a]	200	7,200	200	7,000	—	—	—	14,600	0.10
Cook Islands	—	2,500	—	2,500	—	—	—	5,000	0.03
Fed States of Micronesia	1,500	10,000	200	5,000	—	200	—	16,900	0.11
Indonesia	500	500	500	500	—	—	—	2,000	0.01
Kiribati[a]	—	11,000	—	—	—	—	—	11,000	0.07
Malaysia	1,500	1,500	1,500	1,500	1,500	1,500	1,500	10,500	0.07
Marshall Islands	—	4,000	4,000	4,000	—	—	—	12,000	0.08
Palau[a]	6,500	1,000	1,000	6,500	—	1,000	—	16,000	0.11
Philippines[a]	1,100	1,500	8,100	1,800	4,800	3,600	9,600	30,500	0.20
Tonga	—	4,000	—	30	—	—	—	4,030	0.03
Vanuatu	7,000	7,000	7,000	—	—	7,000	—	28,000	0.19
TOTAL (15 hatcheries)	18,300	50,200	22,500	28,830	6,300	13,300	11,100	150,530	1.00
Grow-out facilities									
Fed States of Micronesia	—	2,000	—	—	—	—	—	2,000	0.06
New Zealand	—	5,000	—	—	—	—	—	5,000	0.15
Palau[b]	2,000	2,000	2,000	14,000	2,000	—	—	22,000	0.64
Samoa	—	—	—	5,000	—	—	—	5,000	0.15
TOTAL (5 facilities)	2,000	9,000	2,000	19,000	2,000	0	0	34,000	1.00

1.3.12. **Macroalgae (seaweeds) – Ulva species (Ulva ohnoi, Ulva tepida)**

Species biology/culture characteristics

Two species of green seaweed in the genus *Ulva*, *U. ohnoi* and *U. tepida*, are commercially cultivated in Northern Australia in land-based ponds for the bioremediation of discharge water from the production of prawns and fish. Both species are characterised by a simple morphology in combination with a high surface to volume ratio, resulting in high growth rates (Figure 1.3.11. 1).

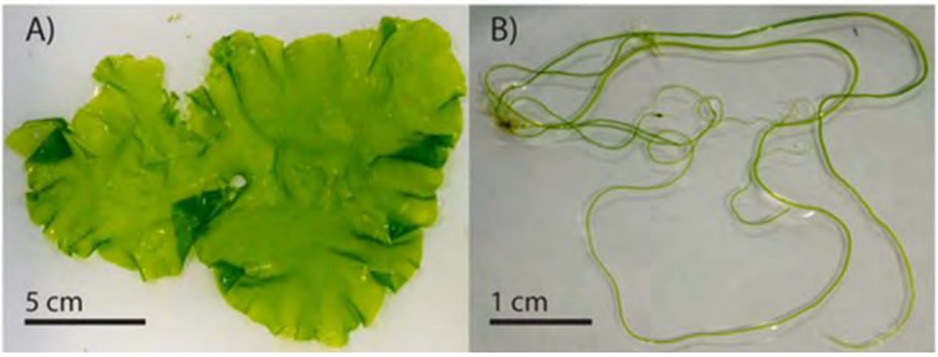


Figure 1.3.11. 1 Morphology of A) *U. ohnoi* and B) *U. tepida*. Figure adapted from Lawton et al 2013.

Ulva ohnoi is a foliose macroalgae with distromatic blades ranging in size from 5 to 20 cm. It has a broad range of environmental tolerance from 15 to 45 ppt salinity and this was the basis for its selection for cultivation. It also has a broad temperature tolerance from 15 ^{o}C to 35 ^{o}C, with an optimum temperature for growth at 26-28^{o}C (Mata et al. 2016). Consequently, it has a broad geographic range from southern Japan in the north to southeast Australia (Sydney) in the south (Lawton et al. 2013). *U. ohnoi* is cultivated as a vegetative form (i.e from broken fragments) in northern Australia without the natural occurrence of cyclic reproductive events as is characteristic for this genus. *U. ohnoi* is an edible seaweed cultivated and sold as dried aosa in Japan and SE Asia.

Ulva tepida (syn. *U. sapora*) is characterised by monostromatic filamentous thalli (Figure 1.3.11. 1 B) ranging in length from 2 cm to 20 cm. This filamentous or tubular morphology has previously been associated with the genus *Enteromorpha*. The taxonomy of the order Ulvales was revised in 2003 and genus *Enteromorpha* combined with *Ulva* (Hayden et al. 2003). *Ulva tepida* has an even broader environmental tolerance than *U. ohnoi* and can be cultivated in salinities ranging from 10 to 55 ppt and tolerates freshwater exposure (Shimada et al 2008). It also has a very broad temperature tolerance up to 40C. It has a geographic range from central Japan to southeast Australia (Sydney) including the Hawaiian Islands (Phillips et al. 2016). *U. tepida* is cultivated as an attached and vegetative form in northern Australia and has a 14-21 day reproductive cycle (Carl et al. 2014, 2016) which can be manipulated to support managed cultivation and harvesting (Praeger and de Nys 2018, Praeger et al. 2019). *Ulva tepida* is an edible seaweed and sold dried as aonori in Japan and SE Asia.

Seaweed production

Global production of seaweeds is in excess of 30 million tonnes (live weight) (FAO 2018), with the majority of production from China (48%), followed closely by Indonesia (39%). China primarily cultivates brown seaweeds (kelps) in temperate waters and provides the majority of these globally, while Indonesia primarily cultivates red seaweeds in its tropical waters. There is no reported production of species of green seaweeds or *Ulva* by the FAO given the relatively low quantity of production compared to the brown and red seaweeds. However, *Ulva* is produced in Japan, Korea and South Africa (> 2000 t live weight) for human food, water treatment and abalone feed (Bolton et al. 2016; Ohno et al 2006). The production of seaweed in Australia is an emerging industry, with no production recorded in the annual ABARES statistics for Australian fisheries and aquaculture statistics (ABARES, 2018). However, in northern Australia harvest of ~25 tonnes of seaweed is expected for 2019, the majority which will be turned into plant biostimulants (Rocky de Nys JCU, pers. comm.).

Research and development (R&D)

There are no fundamental research and development impediments for the commercial production of *Ulva*, or for most species of endemic seaweed in northern Australia. The research and development of endemic species is essentially a technology transfer exercise utilising established methods, particularly from SE Asia. There is an extensive research and development knowledge base and infrastructure platform across the research sector in northern Australia, and Australia more broadly, to provide the technology required for a successful industry, with significant experience in supporting seaweed industries across the tropics. Australia supports the seaweed industry internationally with R&D projects through ACIAR in Indonesia, the Philippines and the South Pacific. ACIAR's research findings are applicable to developing an industry in northern Australia. Research on the reproduction, environmental tolerance, production methodologies, harvest and post-harvest processing of seaweeds would need to be delivered to establish an industry in northern Australia based on market demand. However, the major question to address prior to research and development, is establishing market demand and viability of a seaweed industry in remote and regional coastal environments.

Comment/perspective on what could be solved with R&D, and industry potential growth in NA

The key research and development question revolves around the market potential and business planning for a seaweed industry for northern Australia. There is an extensive international market for tropical seaweeds with a diversity of applications ranging from food to phycolloids and fertilisers. The global value of this market is in excess of USD 8 billion. A first step for industry growth is a comprehensive analysis of the market and costs of production in northern Australia. Seaweed is highly suitable as a crop for remote and regional communities given it can be dried and stored for supply to markets. There are production and supply chain models from the South Pacific and SE Asia that are relevant to northern Australia.

1.3.13. Microalgae – *Haematococcus pluvialis*, Astaxanthin production

Species biology/culture characteristics

Haematococcus pluvialis is a single-celled freshwater organism, with two flagella, commonly found in small fresh water pools and bird baths around temperate regions (Droop, 1955, Czygan, 1970, Boussiba and Vonshak, 1991, Boussiba, 2000, Capelli and Cysewski, 2007). This alga has evolved with a complex life history encompassing four distinct morphological phases. The four phases include a vegetative phase A), palmelloid phase B), palmelloid accumulating astaxanthin in transition to an aplanospore C), and an aplanospore D) (Kobayashi et al, 1997, Shah et al, 2016). It is the aplanospore phase, which is significant, as it is at this stage where under pressure the cells produce higher levels of keto-carotenoid astaxanthin (Goodwin and Jamikorn, 1954, Borowitzka et al., 1991, Zlotnik et al., 1993, Fabregas et al., 1998). It is the keto-carotenoid astaxanthin which is the commercially valuable product from the species. Natural astaxanthin is one of the highest priced pigments on the market, currently evaluated between USD 200 – 500/kg for the whole biomass, and up to USD 12,000/kg for the pigment extract.

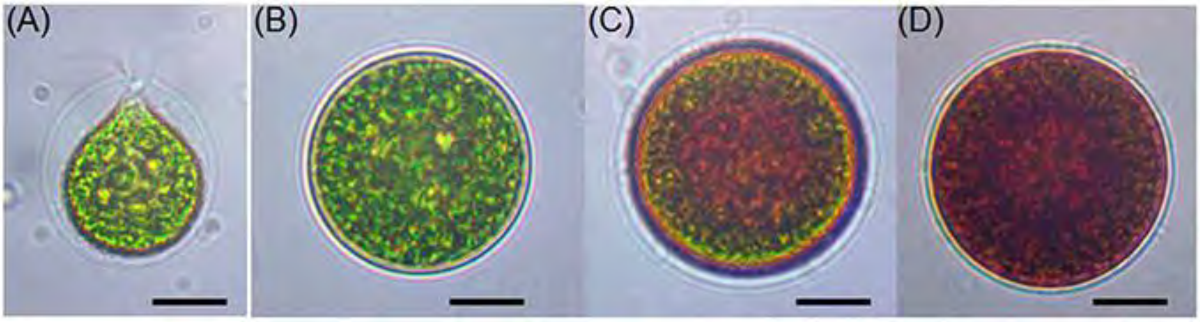


Figure 1.3.12. 1 Photomicrographs of *Haematococcus pluvialis* in the (A) vegetative phase with two flagella, (B) immotile palmelloid formed in unfavourable conditions, (C) palmelloid transitioning to an aplanospore with a thick cellulose wall and enlarged size, and (D) aplanospore with accumulated astaxanthin. Figure source: Shah et al, 2016.

Haematococcus pluvialis or *H. lacustris* is regarded as one of the best sources of natural astaxanthin, accumulating up to 4% of the dry weight of the algal cells (Boussiba, 2000). In the algae the secondary carotenoid is produced as the 3S, 3'S isomer mainly in the form of mono and di-esters (Borowitzka et al., 1991, Grung et al., 1992, Grünewald et al., 1997). Due to its strong antioxidant properties with proven anti-ageing, anti-cancer, anti-inflammatory and immunomodulation effects (Tanaka et al., 1995, Christiansen and Torrissen, 1997, Guerin et al., 2002, Jin et al., 2006, Garofalo et al., 2009, Zhang et al., 2009), natural astaxanthin becomes increasingly common in the nutraceutical, pharmaceutical and cosmetic industry.

Haematococcus pluvialis production and market

In recent years the global market demand for astaxanthin from *H. pluvialis* has been growing drastically due to the increasing consumer awareness of its health benefits. Global market for synthetic and natural astaxanthin overall is estimated at 280 tons valued at USD 447 million in 2014. It is projected that demand will increase production to 670 t valued at USD 1.1 billion by 2020 (Global Industry Analysts, 2015). Fuji Chemical

Company estimated that the astaxanthin market size will hit USD 700 million by 2017. Recently AstaReal/Fuji updated their estimate of the global human grade astaxanthin raw material market, post extraction, at approximately USD 100 million. Sales of natural astaxanthin produced by Cyanotech were reported at USD 19.6M in 2014, which corresponds to 53% share of the US natural astaxanthin market. The size of the nutraceutical astaxanthin market is growing steadily benefiting and increasing the production of natural astaxanthin from *H. pluvialis* since the synthetic product is not yet approved for human consumption. In recent years several manufacturers already have doubled their cultivation capacities. Apart from an increase in existing players' capacities, new producers, in particular from China, have entered the market with significant production capacities (Shah et al., 2016).

Research and development (R&D)

The research and development for this species is mainly driven by the desire to enhance the commercial production of Astaxanthin. In Australia, research in partnership with James Cook University has been comercialised by PacificBio, to produce ReefAsta™, a naturally derived Astaxanthin as a human nutraceutical. Research to date has been focussed on all aspects of the production, from cultivation (Kobayashi et al., 1993, Boussiba, 2000, Hagen et al., 2001, Tripathi et al., 2002, Imamoglu et al., 2010, Gomez et al., 2013), to stressing (Kobayashi et al., 1992, Imamoglu et al., 2009, Lemoine and Schoefs, 2010), downstream processing (Tsang, 2004, Fujii, 2012, Cuellar-Bermudez et al., 2015, Praveenkumar et al., 2015, Panis and Rosales Carreon, 2016) and product development (Guerin et al., 2003, Tachaprutinun et al., 2009, Bonet et al., 2015, Kishimoto et al., 2016).

Comment/perspective on what could be solved with R&D, and industry potential growth in NA

There are still obstacles that need to be overcome to produce Astaxanthin more efficiently from *Haematococcus pluvialis*. The major obstacle to cultivating microalgae at large scale is biological contamination. Biological contamination by other algae or microbes often decimates the yield or destroys the entire culture (Gutman et al., 2011, Carney and Lane, 2014, Dawidziuk et al., 2016). Harvesting, including cell disruption, drying and pigment extraction also remains one of the most challenging issues for commercial microalgae production.

1.3.14. **Microalgae – *Dunaliella salina***

Species biology/culture characteristics

Dunaliella species belong to the phylum Chlorophyta, order Volvocales and family Plyblepharidaceae. This algae is unicellular, photosynthetic and motile, with two flagella and morphologically distinguished by the lack of a rigid cell wall (Ben-Amoz and Avron, 1990). The best-known species of *Dunaliella* are *D. salina*, *D. tertiolecta*, *D. primolecta*, *D. viridis*, *D. bioculata*, *D. acidophyla*, *D. parva* and *D. media* (Borowitzka et al., 1984). *Dunaliella* cells are ovoid, spherical, pyriform, fusiform or ellipsoid with size varying from 5 to 25 lm in length and from 3 to 13 lm in width. The cells also contain a single cup-shaped chloroplast which mostly has a central pyrenoid surrounded by starch granules

(Tafreshi and Shariati, 2009). *Dunaliella* strains are well known for being rich in lutein, zeaxanthin, and β-carotene and *D. salina*, as well as *D. bardawil*, have been particularly widely studied for their rich source of natural β-carotene (Jin and Melis, 2003, Tafreshi and Shariati, 2009).

Dunaliella salina production

D. salina is produced for its high natural content of β-carotene (up to 16% of cell dry weight) (Garcia-Gonzalez et al., 2005) which is processed and then sold in oil, beadlets and water soluble powder for pharmaceutical and nutraceutical applications (Borowitzka, 2013). Most of the *Dunaliella* biomass is produced wild in natural salt lakes. The algae can be produced successfully at a large scale due to its affinity for very high salinity (up to saturation), where no competitors are able to survive. There are large production plants in South America, Israel and Australia. Australia has two plants in WA, which with a total pond area of more than 900 ha are the largest commercial production plants in the world.

Western Biotechnology, Ltd., and Betatene, Ltd., were the first producers of *D. salina* β-carotene in Australia from the mid 1980s, and Nature Beta Technologies (NBT) also commenced production in Eilat in Israel at a similar time. Western Biotechnology and Betatene were acquired by Cognis Nutrition and Health in 1997, and Cognis (now owned by BASF) is the major global producer of natural β-carotene from *D. salina*. Other attempts to produce *D. salina* β-carotene have been made in the United States, India, and China, but most of these were ultimately unsuccessful (Borowitzka, 2013).

The carotenoid is sold in several forms including 1–20% cold water-dispersible powder, "water-soluble" powder, 20–30% suspensions in oil, and as a stabilized whole algal powder. Organic, Kosher, and Halal versions of these products are available. The price of natural β-carotene ranges from about USD 300 to 3000/kg, depending on the product type and the market demand. In 2010, the total market value of β-carotene, both synthetic and natural, was about USD 260 million, and this is expected to increase to over USD 300 million by 2020 (Borowitzka, 2013).

Research and development (R&D)

Most of the research on *Dunaliella* sp. has focussed on the production (Borowitzka et al., 1984, Ben-Amoz and Avron, 1990) and downstream processing of the algae (Mohn, 1980, Naghavi and Malone, 1986, Tanaka, 1990, Leach et al., 1998, Grima et al., 2003, Horiuchi et al., 2003), as well as the extraction (Ruane, 1977, Nonomura, 1987, Bonshtein et al., 2002) and the efficacy of the pigment (Ben-Amoz and Avron, 1990, Tafreshi and Shariati, 2009, Borowitzka, 2013) .

Comment/perspective on what could be solved with R&D, and industry potential growth in NA

Industry is still looking for advances in:

- Enhancing the growth of *D. salina*
- Efficient and economic dewatering and drying
- Economic extraction of β-carotene

Industry potential for growing *D. salina* in northern Australia is relatively low due to its confined production in salt lakes or hypersaline water bodies.

1.3.15. **Cyanobacteria – Spirulina**

Species biology/culture characteristics

Spirulina are multicellular and filamentous blue-green microalgae belonging to two separate genera *Spirulina* and *Arthrospira* and consists of about 15 species. Of these, *Arthrospira platensis* is the most common and widely available spirulina and most of the published research and public health decision refers to this specific species (Habib et al., 2008). *Arthrospira* can occur in soil, sand, marshes, brackish, marine and freshwater, in areas that suit the growth conditions listed below. Usually, species of *Arthrospira* are found in highly saline and alkaline lakes. *A. maxima* in confined to Central and South America, the most notable source is Lake Texcoco in Mexico. *A. platensis* is more widespread than *A. maxima* and found in many areas in Africa and Asia. A third species *A. pacifica* is endemic to the Hawaiian Islands (Vonshak, 1997). Spirulina is considered to be a superfood, containing antioxidants, phytonutrients, probiotics and nutraceuticals. The algae is gaining popularity and was described by the UNESCO as the best food for the future and human-kind's best health product (Soni et al., 2017)

Spirulina production

Worldwide Spirulina production increased from 48,000 t in 2005 to 89,000 t in 2016. With only 0.3% of the total algae production worldwide Spirulina is considered only a boutique market (FAO, 2018). With over half of the production, China is dominating the global Spirulina production. Spirulina is mainly cultivated in open raceway ponds, in which high pH can be maintained, limiting contamination by grazing species. The largest costs in production are labour and nutrient addition (Soni et al., 2017).

In Australia, there is only one commercial culturing facility for *Arthrospira*, Australian Spirulina© based in Darwin. Although the company has been established for over a decade, production at economically viable levels was only achieved with the importation of a foreign strain (from Taiwan), rather than cultivation of a local species. The company viewed their ability to achieve profitability due to the utilisation of a large drying silo, which reduced production costs (Australian Spirulina, 2019). Ninety-five percent of their product is exported to Japan and Taiwan.

Research and development (R&D)

As with other microalgae research of Spirulina has focussed on improving production (Newsted, 2004, Ogbonda et al., 2007, Pandey and Tiwari, 2010, Lucie et al., 2016), downstream processing (Ogbonna et al., 1999, Ankita et al., 2013, Papadaki et al., 2017, Soni et al., 2017), as well as product development (Balasubramani et al., 2016, Yin et al., 2017, Grahl et al., 2018).

Comment/perspective on what could be solved with R&D, and industry potential growth in NA

The economic production of Spirulina in large open raceways is well understood. However, the Spirulina industry could be progressed in the following areas of:

- Cultivation in nutrient rich wastewater rather than supplementation with inorganic nutrients
- Efficient gas exchange in shallow ponds
- Turbulence and algae mixing in shallow ponds
- Downstream processing, in particular economic drying and pigment extraction

1.4. Indigenous aquaculture

1.4.1. **History – failure and success**

There is a long history of RD&E projects in Indigenous aquaculture ventures in northern Australia. These have been reviewed in previous reports (Fleming, 2015; Fleming et al., 2015; Colquhoun, 2017), and selected highlights to inform future RD&E investment are emphasised in this review. Aquaculture is often investigated in communities with a traditional/customary fishing culture, and principles of engaging in RD&E for Indigenous fisheries are applied to both aquaculture and wild fisheries.

Several types of value are identified for Indigenous fisheries, and may include traditional food, production ventures, seafood processing, value-adding, marketing, tourism and recreational fisheries businesses (Colquhoun, 2017). The choice of activity made by community may be focussed on non-financial benefits. Colquhoun (2017), indicates that most Indigenous communities with fishery assets underutilise their fishery resource from a western economic perspective. The study recommended that to create more value for the community, it is important to “first, actively identify and engage communities that hold significant fishery assets, and then secondly, support and guide them to assess their use, build capacity, and develop higher performance options.” Both Fleming (2015) and Colquhoun (2017) could not identify a single successful Indigenous aquaculture venture or business (majority Indigenous board governance, management and investment) in northern Australia.

Attributes of failed projects

Previous attempts to establish aquaculture have focussed on technical and commercial aspects with little inclusion of the social and cultural context (Fleming, 2015). Many projects involved ambitious research in species new to aquaculture in Australia, with demanding husbandry methods to meet species’ biological requirements (e.g. mud crabs, sandfish, giant clams and Cherabin), combined with limited aquaculture technical capacity and inadequate infrastructure in remote Indigenous communities. When considered in the cycles of short-term R&D project funding, often three to five years, the likelihood of successful adoption and creation of a new aquaculture venture was low (Table 1.4.1. 1). In addition, aquaculture ventures have failed due to a lack of market access, and cultural barriers and issues (Colquhoun, 2017).

Table 1.4.1. 1 Failure points associated with past Indigenous aquaculture projects in northern Australia (from Fleming et al., 2015).

Technical/Commercial Aspects		Social/Cultural Aspects	
Supply Side Issues	Demand Side Issue	Cultural Barriers	Development Processes
• lack of technical knowledge causing barriers to production development • lack of adequate startup capital and inadequate planning for time-critical infrastructure investment • lack of robust market research and supply chain analysis	• highly technical work unsuitable for enterprise participants with limited skills and significant education barriers • unrealistic financial expectations (profits and timeframes), • low wages during development coupled with demanding daily operational schedules • crocodile safety concerns excluding diving as part of operational practices	• lack of community control and decision-making • conflict between work attendance and attendance to cultural obligations and demands • inappropriate cross-cultural communication, negotiation and decision making processes	• inadequately short timelines for external managerial, administrative and financial support • lack of long-term planning beyond the tenure of project timeframes, particularly for local governance and business management capacity

Colquhoun (2017), identified the components of economically unsuccessful business models for Indigenous fisheries were:

- Socially focussed business models (cultural governance) without economic governance are not good platforms for commercial ventures
- Representational right to influence or veto economic development initiatives – appropriate for cultural governance and a barrier for economic development
- Lack of broader aspirations for community outcomes that go beyond clan representation – especially where some clans do not have heritage or title to sea country
- Lack of depth in community leadership teams
- Ill-defined and overlapping business and community objectives
- Welfare conflict – choice between economic fishery ventures, shared wealth and employment, and funding the community's needs through the welfare system

In light of the history of failures that occurred regardless of the enthusiasm from Indigenous and non-Indigenous R&D partners, government agencies and funding bodies have re-focussed on frameworks and structures for increasing the opportunity to succeed in establishing Indigenous aquaculture ventures.

Framework for supporting success – RD&E

In 2011, the Indigenous Reference Group (IRG), an advisory committee to the FRDC, established the IRG's RD&E Framework for Indigenous fishery development. It has eleven key principles for Aboriginal and Torres Strait Islanders identified by the Shaping Indigenous Fishing and Aquaculture RD&E Forum held in Cairns in 2011 (IRG-FRDC, 2011). These are supported by five national and community aspirations and IRG strategic priorities, with the Indigenous fishery community as the core stakeholder (IRG-FRDC, 2012; Colquhoun, 2017) (Figure 1.4.1. 1).

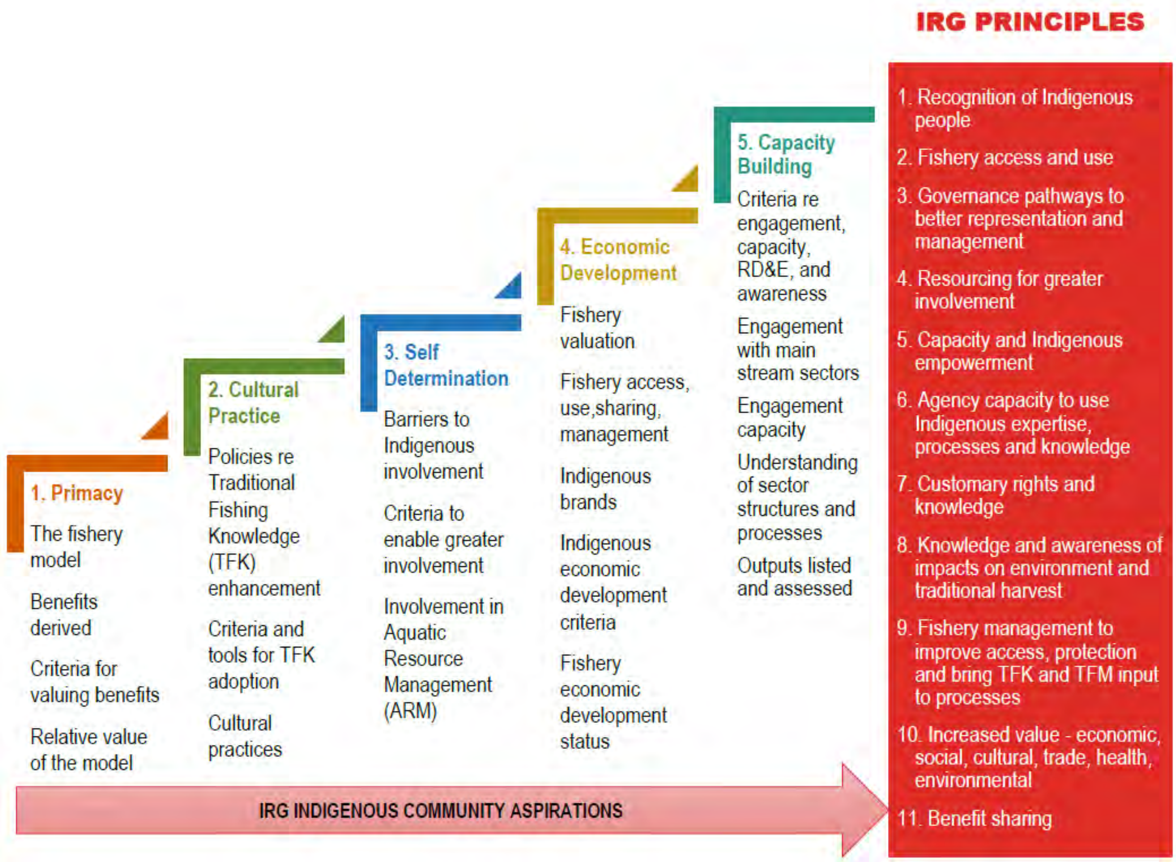


Figure 1.4.1. 1 The Indigenous Reference Group (IRG) for FRDC has established a framework of eleven key RD&E Principles and five national and community aspirations, with a vision to continuously improve Indigenous fishery development (including aquaculture and wild capture fisheries). (Source: Colquhoun, 2017, with more detail of the eleven principles in IRG-FRDC, 2011.)

Fleming (2015) described the implementation of an applied framework, closely aligning with the IRG-FRDC principles and aspirations. The study established an approach with nine key elements for success encompassing cultural, business and market factors (Figure 1.4.1. 2). This was implemented through partnerships to bring the required long-term planning, skills and resources to an aquaculture development plan in the Northern Territory (Figure 1.4.1. 3). This framework was evaluated over aquaculture projects from 2010 to 2015, including black-lip rock oyster, sandfish and giant clam culture, and has application for Indigenous aquaculture development across northern Australia (Fleming, 2015).

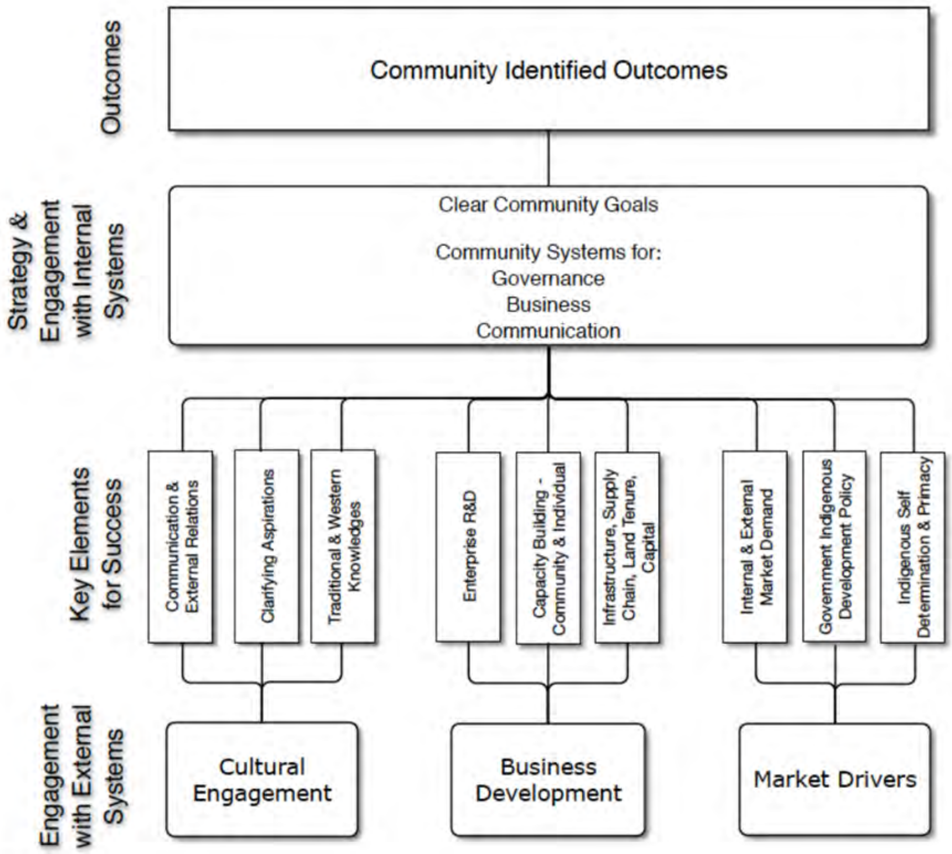


Figure 1.4.1. 2 Implementation framework for critical success factors for Indigenous business/venture development. (Source: Fleming, 2015)

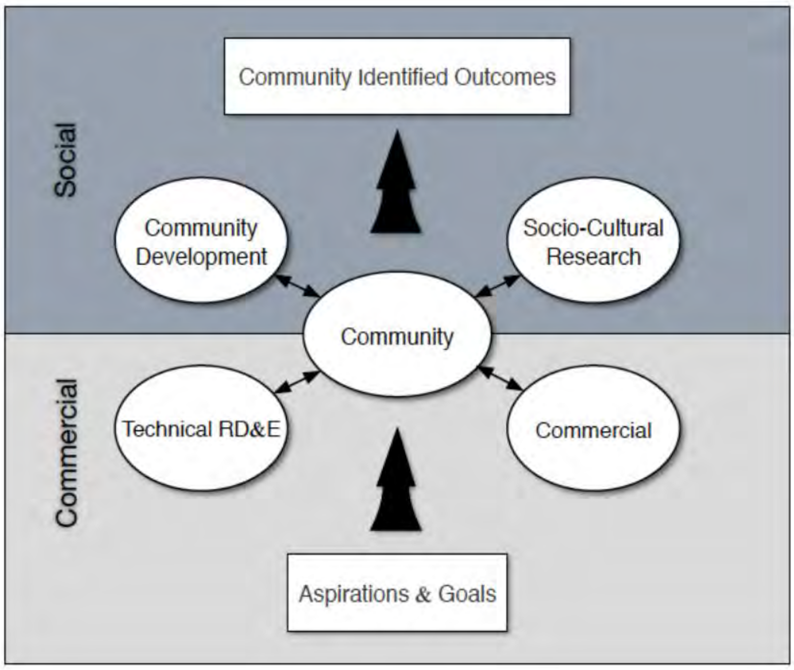


Figure 1.4.1. 3 Collaborative partnership framework used by the Northern Territory Government to engage all key systems for successful Indigenous aquaculture business facilitation. (Source: Fleming, 2015)

Features of successful ventures

The combination of improved frameworks to align cultural and corporate (economic) governance will underpin success (Fleming, 2015; Colquhoun, 2017) (Figure 1.4.1. 4).

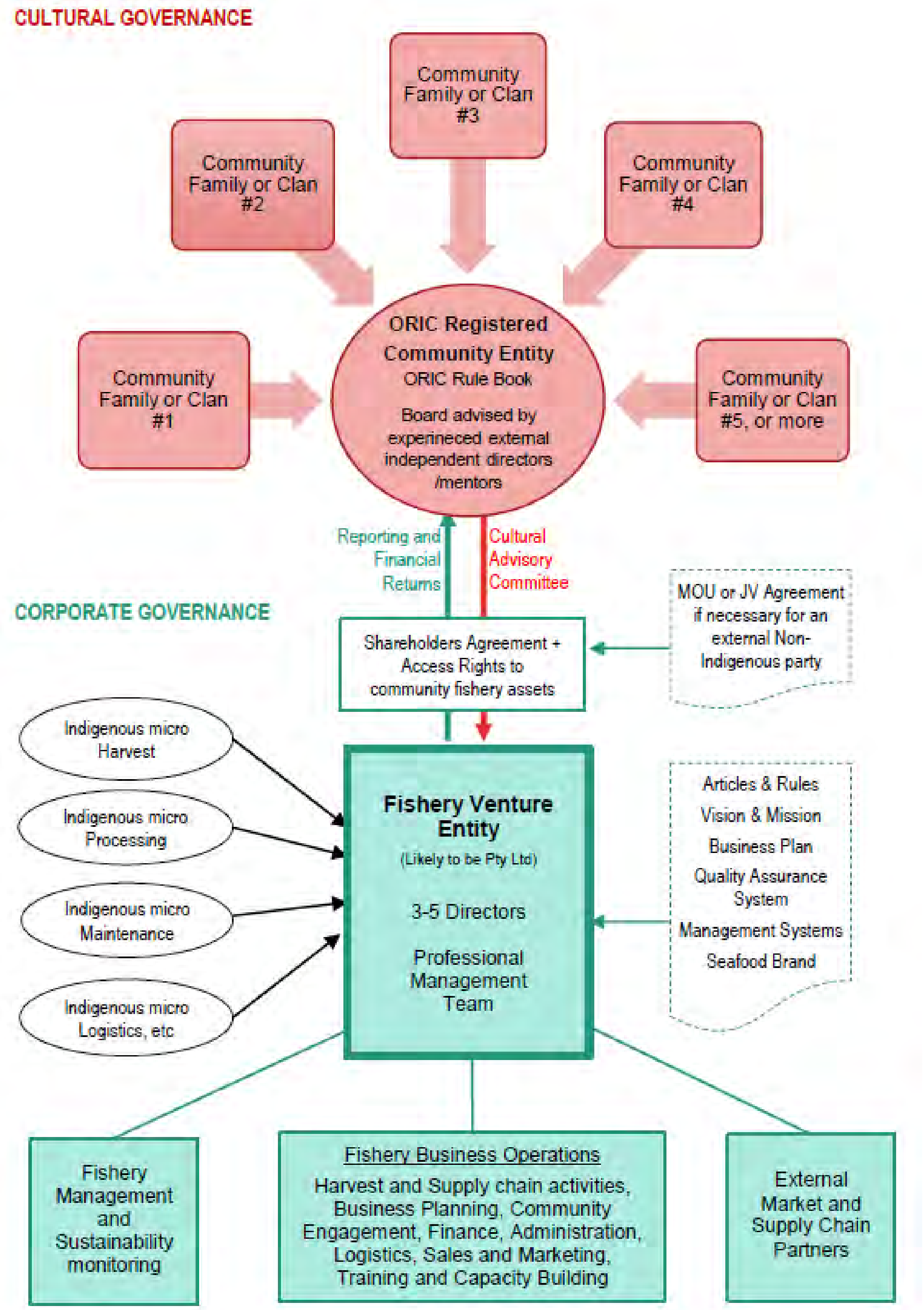


Figure 1.4.1. 4 Recommended model for Indigenous community fishery development. (Source: Colquhoun, 2017)

Business model components for economically successful Indigenous fisheries were defined by Colquhoun (2017) as:

- Registration with Office of the Registrar of Indigenous Corporations (ORIC) – maturity on cultural governance
- Corporate governance - the new element that most communities lack
- Access to new knowledge - the primary driver for economic development
- Microbusinesses – empower community, clans, families and members
- Business Plan for the first 3-5 years
- Fishery venture led by a formally declared and endorsed management team – authority from the venture's board and community

Recommendations
Local capacity in remote Indigenous communities for corporate governance and business management were perceived as key barriers to achieving success in aquaculture ventures and in economic independence more broadly. In terms of developing Indigenous capacity, Fleming (2015) recommended:

- Develop a long term structurally-integrated regionally-based Indigenous fisheries development program – to establish an Indigenous fisheries-based sector across the Territory {which could equally apply across northern Australia}
- Identify business models that integrate both cultural and corporate fisheries business and governance arrangements – while in the interim, pragmatic models continue to be used {concept expanded by Colquhoun, 2017}
- Improve Indigenous participation in fisheries work through further social research into effective engagement strategies
- Develop fisheries agencies' capacity to facilitate Indigenous participation in commercial fisheries
- Develop fisheries agencies' capacity to facilitate fisheries businesses
- Develop industry's capacity to effectively negotiate mutually beneficial commercial arrangements with Indigenous people

Recommendations for developing economically viable ventures made to the IRG and FRDC by Colquhoun (2017), and applicable to other RD&E funding agencies such as the CRCNA, were:

- Implement a plan to identify Indigenous fishery communities across Australia that hold exclusive or non-exclusive rights to, and control of underutilised fishery resources.
- Encourage Indigenous fishery communities, which seek to develop their fishery resources, to establish at least one community corporation registered with the ORIC.
- Encourage each Indigenous fishery community (including local residents and remote Traditional Owners and members) to undertake a formal planning process.
- Encourage community to identify commercial partners, networks and collaborations.
- Empower Indigenous fishery community leaders to attend, contribute to and learn from joint seminars and workshops that include sharing "venture stories".

1.4.2. **Regulatory environment**

A review of fisheries legislation, policy and management strategies for different jurisdictions in Australia revealed only 4% of documents addressed all seven Indigenous fishing principles developed by the National Indigenous Fishing Technical Working Group (NIFTWG) in 2004 (Schnierer et al., 2018). While 53% had no inclusion of these principles.

The National Aquaculture Strategy (DAWR, 2017) explicitly mentions engaging with Aboriginal and Torres Strait Islander peoples on relevant aquaculture issues, and ensuring their participation in setting research priorities and allocating funding (through the IRG) to deliver economic, environmental and social benefit to Indigenous people. In the Northern Territory, the DPIR Aquaculture Policy principles (DPIR, 2018) includes recognition of "the aspirations of indigenous people and [the department] will work with them to facilitate participation in aquaculture development". There is limited reference in documents from Western Australia, with inclusion of Indigenous well-being and consultation in the '*Policy for the Implementation of Ecologically Sustainable Development for Fisheries and Aquaculture within Western Australia*' (DoF, 2002). No explicit mention was made of Aboriginal and Torres Strait Islander peoples in association with aquaculture in documents from Queensland.

At a national level, Schnierer et al. (2018) recommends more explicit inclusion of Indigenous cultural fishing and engagement in policy and legislative documentation. In addition, provisions to protect and enhance Traditional Fishing Knowledge (TFK) are currently lacking (Schnierer et al., 2018). Customary fishing practices have substantial economic and non-economic value for Indigenous communities and limiting access threatens the health, wealth and wellbeing of communities (Smyth et al., 2018).

Another observation of the Schnierer et al. (2018) study was that Indigenous fishers from the Torres Strait perceived a higher risk of non-Indigenous fisheries impacting Indigenous cultural fishing, than counterparts in southern Queensland and New South Wales. It was suggested that this was partly linked to "the raised levels of animosity and anxiety that Indigenous participants have with respect to fisheries agencies and a feeling of disengagement and lack of acknowledgment of rights" (Schnierer et al., 2018). This is an important context for consideration when engaging with Indigenous communities to develop successful Indigenous aquaculture, as well as wild fisheries ventures in the Torres Strait. With expansion underway for many established aquaculture sectors, and new sectors planned, it is a critical time to maintain participation and engagement with Aboriginal and Torres Strait Islander peoples in northern Australia to avoid real or perceived issues associated with cultural heritage, title and rights.

1.4.3. **Case Studies**

There were two case studies of Indigenous aquaculture, both with current activity, included in the project commissioned by IRG and undertaken by Colquhoun (2017).

The first was the Yagbani Aboriginal Corporation (YAC), established by the Warruwi community in 2011 as a community not-for-profit business. The Warruwi community, South Goulburn Island, NT, has been involved in different aquaculture activities since 2000, along with the wild harvest of beche-de-mer (also known as trepang, sea cucumber or sandfish *Holothuria scabra*). There are five clan groups on the Goulburn Islands: Manggalgarra, Meyirlgulidj, Murran, Namarawaidja and Yalama. From 2000, prior to Yagbani's establishment, aquaculture RD&E investigated sponges, beche-de-mer, black-lip rock oysters and giant clams. Research was supported by the Darwin Aquaculture Centre and focussed on working with Indigenous women (Fleming, 2015). Tasmanian Seafoods Pty Ltd has operated in the wild fishery for sandfish since the 1980s and has been investing in R&D for sandfish hatchery production and release to the sea for ranching. A Memorandum of Understanding was established between Tasmanian Seafoods and Yagbani which includes a microbusiness opportunity for Warruwi people to harvest the ranched sandfish. In addition, Yagbani is active in R&D with black-lip rock oysters. The Yagbani project was identified as having significant risk, in relation to commercial objectives, because of a lack of business capacity in the microbusinesses, and Tasmanian Seafoods was seen as critical to meet capacity gaps (Colquhoun, 2017).

The second is the Aarli Mayi Aquaculture Project in the West Kimberley, WA, a joint venture between the Dambimangari, Bardi Jawi and Malaya People, with Maxima Fish Farms Pty Ltd. "Aarli Mayi" is the Bardi language phrase for food from the sea. The Aarli Mayi Aquaculture Project is developing marine aquaculture initiatives in edible rock oysters and finfish. They have a multi-species finfish licence that includes barramundi, cobia, barramundi cod, saddletail snapper, coral trout, flowery rockcod, camouflage grouper, and giant grouper. The lease is 369 ha in the Kimberley Aquaculture Development Zone (KADZ) for up to 5000 tonnes p.a. They also have potential to farm prawns, Cherabin and marine ornamental (aquarium) fish. The project is seeking start-up finance to develop the aquaculture opportunities available and worked with Price Waterhouse Coopers on the scope of a full feasibility study. The project met the majority of the IRG-FRDC framework criteria for a successful economic fishery venture outcome (Colquhoun, 2017).

1.4.4. Prospective species

In addition to a well-planned, long-term and locally resourced program, as described above, the successful establishment of Indigenous aquaculture ventures would be enhanced by selection of an established species such as barramundi, prawns or redclaw. Coupled with a relatively low technology, such as an extensive pond production system, this would allow remote communities to acquire aquaculture skills, before exploring more technically challenging options.

Australian researchers have been active in supporting remote coastal communities internationally, often through ACIAR projects, to improve livelihoods with aquaculture ventures and microbusinesses. There is an opportunity to translate low technology industries from international contexts to Australia, such as mabe pearls (half pearls used for handicraft production, ACIAR project FIS/2016/126), seaweed, sandfish, giant clams, and sponge culture. Many of these have been tested unsuccessfully in the past. However, with a strong business case and the appropriate frameworks in place, the technology is available to test again. There are also new species options on the horizon, which will require on-going collaboration in training and technology transfer, including spiny lobster growout, Cherabin, black-lip rock oysters, and potentially silver cobbler.

2. BIOSECURITY IN NORTHERN AUSTRALIA

2.1. Biosecurity & Aquaculture

Biosecurity is the system of procedures and measures that can be implemented at any geographic or enterprise level to mitigate risk of exotic and endemic species introduction and disease spread. Biosecurity has the purpose of protecting natural environments, human and agricultural health, and the sustainability and market advantage of primary agricultural industries (Simpson & Srinivasan, 2014). For aquaculture, biosecurity mitigates disease transfer and amplification within and between jurisdictions and farming enterprises (AQUAPLAN 2014-2019). Australia's biosecurity system has played a critical role in reducing such risks and ensuring that Australia remains one of few countries in the world free from many of the world's most severe pest species and diseases (Commonwealth of Australia, 2015). However, while geographical isolation has played a key role in Australia's freedom from many such pests and diseases, our island isolation is changing in an increasingly connected world (Commonwealth of Australia, 2015).

Marine biosecurity is of considerable importance in Australia due to our island geography. The marine biosecurity threat has a unique dimension borne as a by-product of the maritime shipping industry through spread of exotic and endemic pest species via inappropriate release of ballast water, shipborne biofouling contamination of local environments, and even garbage and abandoned fishing vessels and their remnants (ABC News, 2019). The connectivity of the world's oceans leaves open the possibility of threats to marine biosecurity posed by the migration of exotic and endemic marine species encouraged by broad scale changes in the marine environment due to climate change (Commonwealth of Australia, 2015; DAWR, 2015). The impacts of such foreign 'pest' species incursions on local species and populations can be through direct predation, competition for resources, and through introduction and spread of pathogens to which local stocks are naïve. Moreover, environmental changes can also increase the marine biosecurity threat by stimulating disease outbreaks from endemic pathogens through enhanced environmental stress on local host populations (Sub-Committee on Aquatic Animal Health, 2016). The difficulty in determining which pest and pathogen species may arrive and become established, and in predicting the consequences of their presence, is significant (DAWR, 2015). The marine biosecurity threat is further heightened by the many unknown pathogen species that pose risk (Murray & Peeler, 2005), and by nature of the limited knowledge available on the distribution and epidemiology of certain pathogen species (Sub Committee on Aquatic Animal Health, 2016; Jerry, 2018).

For aquaculture industries, the largest threat is posed by pathogens, both exotic and endemic, infecting naïve cultured stocks. It has been estimated that disease outbreaks cost the global aquaculture industry $US 6 billion annually and represent the major enterprise-level risk (Brummett et al, 2017). Pathogens can enter the country via the marine routes just described, or by passing through the quarantine system within globally traded and transported products. Once across the border, pathogens can transfer to aquaculture enterprises through multiple routes including pathogen infected raw food products, contaminated feed ingredients, and staff or equipment harbouring pathogens that then pass into the farming processes (Sub-Committee on Aquatic Animal Health, 2016a, 2016b). The spread of infectious diseases has been clearly identified as a significant threat to the profitability of Australia's aquaculture industries, particularly so for emerging and expanding sectors (AQUAPLAN 2014–2019).

Biosecurity breaches from pathogens can have catastrophic impacts in aquaculture, through direct losses of farmed stocks due to disease mortalities, but also due to the required regulatory response in controlling exotic incursions into natural environments and other aquaculture operations. Biosecurity failures leading to the spread of the highly pathogenic White Spot Syndrome Virus (WSSV) into naïve farmed prawn populations and jurisdictions illustrate both the direct costs to tropical aquaculture production that can arise from mortality events (Walker and Mohan, 2009) and the broader costs to industry and government associated with regulatory responses to contain the pathogen spread and ongoing survey to confirm 'freedom' of the pathogen post-breach (Ridge Partners, 2017). The WSSV incursion in South East Queensland in 2016 is a case study of the direct economic impacts of biosecurity breaches. This incursion resulted in an estimated loss of $49.5 million to prawn farms and the predicted loss of 122 jobs (Commonwealth of Australia 2017). Queensland DAF had 160 departmental staff involved in the white spot response, used 6.8 million litres of chlorine, and took 174 days to complete destruction and decontamination work. The Queensland Government committed approximately $18M for these operations in 2016-17 and further committed $9M over the successive two years. Queensland spent $140,000 on the "be a mate, check your bait" social media campaign to mitigate risks of WSSV spread. The Australian government provided over $21M to assist farmers and control the WSSV spread. Seven prawn farms were completely devastated in the 2016/17 season and underwent fallowing conditions (effective shut down) until May 2018. These figures still do not capture the full economic impacts of the 2016 WSSV incursion, with costs associated with aquatic animal health pathogen testing, and potential losses from fisheries production in Moreton Bay, just a couple more examples of the known and potentially wider costs.

Beyond the direct costs of exotic pathogen breaches, the establishment of exotic pathogens within natural populations can alter a nation's health status based on the OIE listing of pathogens (Jones et al, 2012), which can in multiple ways impact the saleability and market opportunity for farmed products (AQUAPLAN 2014-2019; Commonwealth of Australia, 2015). Loss of pathogen freedom status can reduce the market for Australian products by way of trade constraints imposed by receiving countries or by declining marketability based on lowered perception product quality, particularly so if providing 'premium' products (Commonwealth of Australia, 2015). Certainly, the ABFA (Australian Barramundi Farmers Association) considers the 'low' disease status of Australia as a competitive advantage for the industry (Commonwealth of Australia, 2016b). Moreover, establishment of exotic pathogens in natural environments can significantly impact wild fisheries, and management restrictions such as the imposition of exclusion zones can also add significant costs for both government and the fishing and aquaculture industries (Inspector General of Biosecurity 2017; State of Queensland, 2018). Even if considered only from an economic perspective, biosecurity makes good business sense (Commonwealth of Australia, 2015).

Biosecurity breaches in aquaculture can also manifest through spread of endemic and emerging pathogens that are absent in one region, industry or enterprise, to another (AQUAPLAN 2014-2019). There are numerous examples of disastrous disease outbreaks spreading from one enterprise or farming region to another, with several examples from temperate and subtropical Australia including the abalone Viral Ganglioneuritis outbreaks in 2005 (Gavine et al, 2009), the Pacific Oyster Mortality Syndrome (POMS) episodes in 2010 (Davis, 2016), and the prawn White Spot Syndrome Virus (WSSV) episodes in 2016 (Inspector General of Biosecurity 2017). Such disease contagions have potential to be caused, hastened or intensified by failures in biosecurity.

Escapees from aquaculture enterprises also posit risk of disease contagion and genetic pollution to wild populations. One example was observed with escapees of farmed barramundi into the Hinchinbrook Channel following damage inflicted on sea cages during a tropical cyclone in 2011 (Noble et al, 2014). Escapee events can have impacts on aquaculture by nature of public concerns of wild populations being ‘genetically polluted’, or put at risk due to exposure to farm-borne pathogens to which the wild stocks have higher susceptibility, and potentially via disease spread if other aquaculture operations in the vicinity possess populations naïve to the pathogen. However, there are no confirmed examples in Australia of disease passing from aquaculture populations to the natural environment (Commonwealth of Australia, 2016b).

2.2. The Biosecurity System

2.2.1. Biosecurity Regulation in Australia

The Department of Agriculture and Water Resources (DAWR) has primary responsibility for managing Australian biosecurity. The Australian Government implements biosecurity measures to maintain an appropriate level of protection (ALOP). ALOP as expressed in the Biosecurity Act 2015 is a high level of sanitary and phytosanitary protection aimed at reducing risk to a very low level, but not zero (Australian Government, 2016a). There are three key biosecurity activities, prevention, eradication and containment. Governments have the primary responsibility during the prevention and eradication stage, while the owner (public or private) has primary responsibility in protecting assets from established pests and pathogens (Commonwealth of Australia, 2016a).

Aspects of biosecurity associated with aquatic animal health in Australian are managed within the wider national biosecurity governance framework, as outlined in Figure 2.2. 1. A range of committees focused on aquatic animal health and the aquaculture and fisheries sectors consult and report to the Animal Health Committee (AHC). The AHC then has upward reporting responsibilities to the national, state and territory primary industries and environments departments.

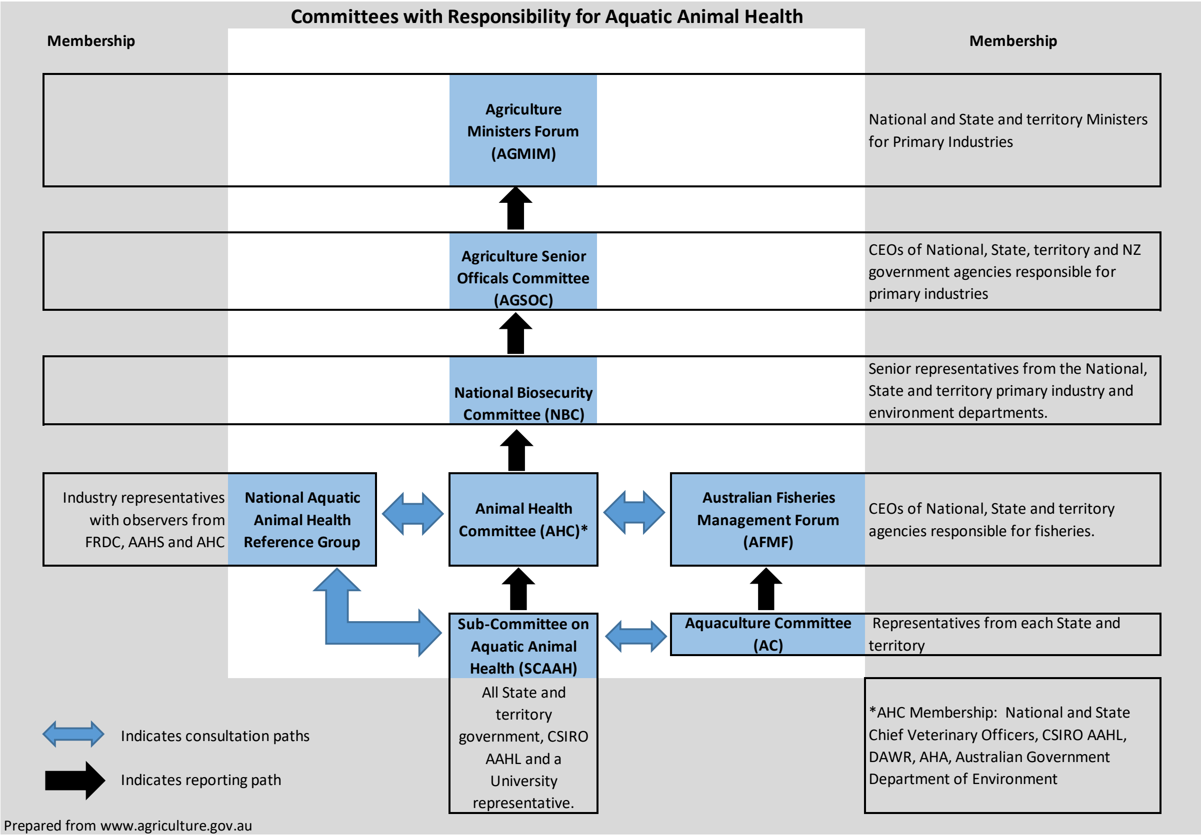


Figure 2.2. 1 Schematic showing the governance structure for Aquatic Animal Health in Australia.

2.2.2. Biosecurity Regulation by northern Australia Jurisdiction

Management of pest and pathogen species across Australia is complex due to regulation by various State, Territory and Federal legislation. Each jurisdiction may have their own legislation, regulations and strategies for managing pest species, pathogens and animal translocations consistent with their constitutional responsibilities (Table 2.2. 1). Further information on the development and jurisdictional management of the Australian biosecurity system can be found in Appendix 1.

2.2.3. Biosecurity Breach Prevention & Response

Biosecurity is best managed through preventative measures, and this is where most of the biosecurity focus and effort must be. However, effective response measures must also be considered if biosecurity is breached, and in some instances, well-considered and well-targeted responses can be effective in mitigating or even eliminating the long-term impacts of the breach. Prevention measures largely comprise the governance frameworks of government and industry institutions, policies, regulations, and industry plans placed to ensure biosecurity across industry, regional and national levels. The effectiveness of such measures depends on both the effectiveness of planning, compliance, and how well jurisdictions work together. Other critical supports to these governance frameworks are the institutions that provide the needed diagnostic services and the level of engagement with community to encourage understanding and compliance to avert biosecurity breach.

Table 2.2. 1 Relevant state and territory legislation, plans, strategies, policy and committees related to biosecurity management

Jurisdiction	Biosecurity legislation	Relevant plans, strategies, policy and committees
Commonwealth	Commonwealth Biosecurity Act 2015	AUSTVETPLAN (Australian Veterinary Emergency Plan)
		Marine Pest Plan 2018- 2023
		Northern Australia Quarantine Strategy (NAQS)
		Intergovernmental Agreement on Biosecurity. The National Biosecurity committee (NBC)
		National Biosecurity response agreement (NEBRA)
		Marine Pest Sectoral Committee (MPSC)
		The Aquatic Consultative Committee on Emergency Animal Disease (AqCCEAD)
Northern Territory	Commonwealth Biosecurity Act 2015	NT Biosecurity strategy 2016-2026
Queensland	QLD Biosecurity Act 2014	QLD Biosecurity Regulation 2016
		Queensland Biosecurity Strategy 2018-2023.
		Biosecurity Queensland Ministerial Advisory Committee (BQMAC)
Western Australia	Biosecurity and Agriculture Management Act 2007	WA Biosecurity Strategy 2018-2023
		Recognised Biosecurity groups (RBG's)

Response measures also fit within the overall governance framework and focus on eradication and containment of localised breaches. Effective engagement with the affected industry enterprises and organisations, and with the public are critical in effective response. AQUAVETPLAN is the Australian Aquatic Veterinary emergency plan. It consists of a series of manuals that outline approaches to for response to aquatic disease. Two manuals address diseases of tropical species namely WSSV that affects crustaceans and Viral Encephalopathy and Retinopathy (VER) that affects marine fish species. There are no chapters prepared for diseases of tropical oyster species or for a range of bacterial or viral infections recognised on the national list of reportable diseases and the national biosecurity guidelines for Australian Barramundi farms (Future Fisheries Veterinary Service 2017) that are confirmed to be, or potentially are, pathogenic to barramundi. Although the imported frozen prawn risk assessment identifies pathogens that could potentially be imported in viable form in uncooked prawns, there is no prepared response plans for many of these pathogens within the AQUAVETPLAN.

Response cost is shared between national, state governments and industry and is governed by individual industry emergency animal disease response arrangements (EADRA). The development of an 'Aquatic Deed' governed by EADRA between major aquaculture industries and government will be integral in regard to a formal biosecurity response (Animal Health Australia, 2019).

2.2.4. Biosecurity Supporting Systems

National Association of Testing Authorities (NATA) accredited laboratories provide diagnostics for surveillance, with capacity and role in the rapid diagnosis for response to disease outbreaks of national importance. Surveillance testing is critical in targeted prevention by the detection and exclusion of infected high-risk imports and in monitoring the containment status of a disease following an outbreak. Rapid diagnostic testing is required in the assessment of the disease status of live animals for breeding, translocation and stocking in grow-out systems and critically on occasions when disease is suspected, with identification required to determine the response.

2.2.4.1. Surveillance

The Department of Agriculture and Water uses surveillance and inspection to screen the entry of millions of people, parcels, vessels animals and plants coming into Australia each year. (Biosecurity Australia, 2018). Import of plant or animal products into Australia requires inspection by DAWR and is subject to Biosecurity import conditions. Biosecurity Import Conditions Systems (BICON) details the import conditions for over 20,000 commodities (Biosecurity Import Conditions Systems, 2019).

The import of infected uncooked seafood is one of the highest risk pathways for the introduction of exotic disease into Australian aquaculture systems (Commonwealth of Australia, 2017). Current import restrictions on a selection of uncooked seafood and ornamental fish are listed in Table 2.2. 2. The restrictions on any product is subject to change and updated as required to meet Australia's ALOP to reduce the biosecurity risk to a very low level. In the case of uncooked prawns 'Unrestricted risk' where no import restrictions are imposed on import is deemed inadequate to meet ALOP (Commonwealth of Australia, 2017). Actions to meet ALOP are not applied consistently across animal production (Landos et al, 2017). Within Australia, jurisdictions have the option of enforcing stricter actions than the National requirements. For example, Tasmania has applied stricter regulation on the import of Salmon than applied at the National level.

Table 2.2. 2 Current Australian quarantine policy on relevant live or uncooked seafood products which have prohibitions on use in aquaculture or by fishers. Information sourced from (http://www.bicon.agriculture.gov.au)

Product	**Form**	**Permitted entry**	**Import conditions**
Molluscs (not oysters or snails)	Frozen	Yes	Subject to import permit approval, including declaration that product will not be used for bait, aquaculture or animal feed.
Prawns (whole)	Frozen	No	Prohibited (with few exceptions)
Prawns (peeled*)	Frozen	Yes	Product from approved country list and subject to import permit approval. Declaration that product will not be used for bait, aquaculture or animal feed.
Prawns (par cooked)	Frozen	Yes	
Prawns (Highly processed)	Frozen	Yes	
Fish (ornamental)	Live	Yes	Fish from approved country list and subject to import permit approval. Declaration that product will not be used for feeding aquarium fish, bait, feeding of aquaculture stocks or aquaculture purposes.
Fish (e.g. Fillet)	Frozen	Yes	Subject to import permit approval. Aquaculture not mentioned in declaration.

Even with safeguards in place, some imported goods which contain disease will at times enter Australia. A senate report (Commonwealth of Australia, 2017) on biosecurity risk associated with imported seafoods listed that the main secondary risk pathway for infected material which has entered Australia is via the use of the uncooked product as feed in research or commercial operations (e.g. broodstock feed), waste products from processing and use as bait or berley by fishers. The report states that the likelihood of an imported prawn (as processed or unprocessed feed) which is introduced into a prawn farm environment being consumed is 'certain'.

2.2.4.2. Accredited Laboratories

The Australian Animal Health Laboratory (AAHL) in Geelong is a critical component of Australia's biosecurity network. AAHL has the primary function of researching emerging infectious disease and in diagnostics which require the highest level of biosafety. AAHL is accredited with the National Association of Testing Authorities (NATA) to provide diagnostics for surveillance, with capacity and role in the rapid diagnosis for response to disease outbreaks of national importance. The Diagnostic Emergency Response Laboratory (DERL) which opened in 2008, plays a key role in the investigation of exotic and emergency disease outbreaks, the capacity for accurate and rapid analysis enables the implementation of control or response strategies as required. AAHL aids countries in the Asia Pacific region to control and eradicate disease by operating as a World Organisation for Animal Health reference laboratory (OIE) and FAO Collaborating centre. This International role provides AAHL with vital information on the threat and potential management strategies of diseases exotic to and neighbouring Australia. AAHL have capacity for a range of diagnostic tests which facilitates import and export of live animals. Imports into Australia must comply with DAWR protocol relevant to the country of origin. There is a mandatory requirement that any analysis for exotic pathogens is completed by a NATA accredited laboratory. There are Government, University and private NATA accredited laboratories. Public laboratories are most likely to be multi-purpose, which means there is likely to be a significant duration between shipment of samples and receiving results. All positive tests for exotic pathogens must be sent to AAHL for confirmation testing.

In northern Australia there are only two NATA accredited laboratories with approval to test for exotic pathogens in aquatic species, the JCU AquaPATH at James Cook University, Townsville and the government run Berrimah Veterinary Laboratory in the Northern Territory.

2.2.4.3. Rapid Diagnostics

Timely turnaround of disease diagnostic results is critical to enable commercial businesses to undertake many appropriate management actions, such as to assess the pathogen and disease status of an animal when disease is suspected, approvals to translocate are needed, or if disease response actions are required. Rapid diagnostic testing typically refers to such timely turnaround times for testing where results can be provided to businesses within days to a week from sampling. Disease screening to assess the health status of live animals is important and at times mandatory across various life stages of the cultured animal. Wild broodstock are screened for disease prior to selection (or rejection) as breeders in commercial hatcheries or research scale breeding programs. The broodstock are screened for the presence (and load) of a range of endemic and exotic diseases. The offspring or 'seedstock' of broodstock are screened prior to transport from the hatchery to grow out, according to the receiving jurisdictions translocation policy.

Under revised translocation policy in QLD any prawn movements, including within QLD and inter-enterprise, must meet the outlined requirements (State of Queensland 2018). Translocation policies for aquatic animals vary between species and jurisdiction (Table 2.2. 3). When disease (exotic or endemic) is suspected to be present in an aquaculture enterprise there is a requirement for rapid turnaround of results to enable identification and targeted response.

Table 2.2. 3 Current policy on translocation on the movement of aquatic animals

Jurisdiction	**Information on translocation policy**
Northern Territory	https://dpir.nt.gov.au/fisheries/aquaculture-policies
Queensland	https://www.business.qld.gov.au/industries/farms-fishing-forestry/fisheries/aquaculture/policies-licences-fees/moving-aquatic-animals
Western Australia	http://www.fish.wa.gov.au/Sustainability-and-Environment/Aquatic-Biosecurity/Translocations-Moving-Live-Fish/Pages/default.aspx https://www.aquaculturecouncilwa.com/files/3314/1145/8871/Translocation_of_Barramundi_FMP_159.pdf

2.2.4.1. Biosecurity exercise response

Simulated biosecurity response exercises are intended to strengthen relationships between the various stakeholders and provide an understanding of the complexity of the operating environment and planning required to implement a response. The most recent simulation exercise was initiated by a recommendation from the 2015 Review of National Marine Pest Biosecurity, and was conducted in Sydney in 2018 and involved a range of stakeholder meetings to discuss impacts and response to marine pest emergencies at the Sydney port. The hypothetical scenario was the response to the presence of the invasive indigo striped oyster (Animal Health Australia, 2018). Former simulation exercises have been conducted, with a 2012 exercise involving the South Australian oyster industry. Within Northern Australia, simulations for the prawn and redclaw industries were conducted in Queensland, and for the pearling industry in Western Australian between 2000-2004 (Anon. 2004). No simulation exercises have as yet occurred in Northern Territory (Anon 2004). Notably, the arrangements for undertaking such simulation exercises for emergency aquatic animal diseases are somewhat vague. Whilst the Department of Agriculture and Water Resources supports the undertaking of simulated biosecurity response exercises, initiation of these exercises falls to other entities, such as state government departments, local councils and potentially organisations such as Animal Health Australia. An aquaculture specific emergency response exercise in northern Australia is recommended.

2.3. Pathways of Biosecurity Breach in Aquaculture

Biosecurity breaches can occur through multiple pathways for different aquaculture industries and operational components (Sub-Committee on Aquatic Animal Health, 2016a). For sea-based culture industries, such as fish cage or mollusc culture in systems which reside in natural marine water bodies, there are direct risks of endemic or exotic pest species and associated pathogen incursions, and the means for controlling such incursions in these open production systems are limited. Such pest or pathogen incursions of natural environments and populations can also impact land-based aquaculture systems. The accidental or deliberate introduction of foreign species that outcompete or spread disease to 'broodstock populations' that supply seedstock to these farming operations can impact seedstock supply to closed and land-based farming systems. Wild animals proximal to the farming system, which harbour exotic or emergent endemic diseases to which the cultured stocks are naïve, also pose risk of biosecurity breaches through water intakes, vector transfers from natural to culture environments, and staff or equipment transfer of disease when moving to and from the farm operation. Land-based aquaculture industries using open ponds are at risk from either the host 'itself' and the potential diseases that may occur from importation of foreign or exotic live animal species, or from diseased natural stocks that may derive from an earlier breach of biosecurity; one example being exotic pathogen infected raw-food products being used as bait in a natural water body, which subsequently infects wild stocks, and which pose many of the risks just noted due to proximity of infected animals to naïve cultured populations (Diggles, 2017).

All aquaculture industries are at risk from any products, such as live feeds, frozen feeds, or other additives to the culture systems, which are infected with foreign or exotic pathogens of which the culture stocks are naïve, and which could introduce disease into the farming system (Sub-Committee on Aquatic Animal Health, 2016b). One pathway considered high risk is via the importation of raw seafood products, such as 'green prawns' (Commonwealth of Australia, 2017). The key concern is that these products are used as bait or berley rather than for the intended use as a product to be cooked and consumed by humans (Diggles, 2018). The risk from seafood products that are cooked or processed is considered negligible in comparison. Notably, the ALOP for imported salmon, chicken or pork products has resulted in imported products having to be cooked (with few country exceptions), which contrasts the current ALOP requirements for imported prawn products (Commonwealth of Australia, 2016b).

Though few confirmed cases, commercial sabotage is another potential risk pathway. This can occur from deliberate introduction of infected stocks (Jones, 2012), either directly into aquaculture operations or into natural waterways proximal to farming operations or from the tampering of containment structures to release cultured stocks in to the natural environment (Dias, 2012). The interrelation of potential pathways presenting biosecurity risk, coupled with the breadth of potential pest and pathogen species posing risk, results in a complex network of pathways posing risk to aquaculture operations.

2.4. Key Biosecurity Risks for Northern Australian Aquaculture

There is significant and likely increasing biosecurity risk for current and future aquaculture developments in northern Australia (Commonwealth of Australia, 2016b). Global megatrends are predisposing biosecurity systems of all jurisdictions to potential megashocks (Simpson & Srinivasan, 2014). Increasing global trade and interconnectivity, climate change and increasing farming intensification are megatrends that foreshadow 'a bumpier ride ahead' for the Australian biosecurity system, and certainly pose more biosecurity risk to northern Australia (Commonwealth of Australia, 2015). There are many exotic and endemic pest and pathogen species that are currently identified by the jurisdictions of northern Australia as significant biosecurity threats, and examples of those of relevance to current and future aquaculture industries are presented in Table 2.4. 1 and Table 2.4. 2.

The greatest biosecurity risk posed to sea-based mollusc industries are from pathogen-borne diseases. For the highest value northern Australian mollusc industry, the pearl oyster industry, significant risks are posed by exotic (e.g. Iridoviruses, Akoya Oyster Disease) and foreign-endemic pathogens (e.g. *Perkinsus olseni* into Northern Territory) (DigsFish, 2018). The Pearl industry is also at risk from Oyster Oedema Disease (OOD), which is reported to manifest in ways consistent with an infectious pathogen contagion, however, the causative agent of the disease is yet unconfirmed (e.g. Oyster Oedema Disease - OOD) (Commonwealth of Australia, 2016b, Goncalves et al. 2017). The key risk pathways for entry of these pathogens into culture systems are via mollusc pest species introductions from biofouling incursions of natural waterways, domestic translocation of infected culture populations, and via infectious 'mollusc' products being used for recreational purposes in the natural waterways proximal to pearling operations, such as mussels being used as fishing bait or ground-up as berley (DigsFish, 2018).

As for sea-based mollusc industries, the greatest risk for sea-based fish industries is also pathogen borne diseases. For barramundi, a species cultured across a diverse range of farming systems including sea-cages in northern Australia, the most significant biosecurity risks are posed by exotic diseases such as 'scale-drop syndrome', 'pot-belly disease' and the iridoviruses and the formerly exotic bacteria-like *Edwardsiella ictaluri* (Kelly et al. 2015), which are endemic to Asia (Irvin et al. 2018; Hernandez-Jover et al. 2017). The highest risk pathways for entry of these pathogens, as identified by the Australian Barramundi Farming Association, are through infected imported frozen products transferring into natural waterways (or even potentially directly into farming systems), which could then pass onto to sea-cage or even open-pond land-based operations (Commonwealth of Australia, 2016b; Hernandez-Jover et al. 2017).

Risks for land-based saltwater fish industries are similar to the sea-based fish industries. For freshwater land-based fish aquaculture operations there are high risks posed by exotic pathogens introduced with ornamental fish (Interim Inspector-General of Biosecurity 2012, Commonwealth of Australia, 2014, Becker et al. 2017), with some viewing the ornamental fish trade as being poorly regulated (Commonwealth of Australia, 2016b). Popular ornamental species, such as cichlids and gouramis, can harbour pathogens (ISKNV-like viruses, iridoviruses) for which many native and cultured Australian freshwater and marine fish species, including barramundi and grouper species, are highly susceptible (Australian Department of Agriculture, 2014; Commonwealth of Australia, 2012; Hernandez-Jover et al. 2017; Commonwealth of Australia, 2014; Becker et al. 2017). Release of infectious ornamentals, and release of associated infectious materials from these ornamental fish (e.g. discard of dead fish, fish used as bait or berley), into the natural waterways opens multiple pathways of biosecurity breach for these culture fish species. Similar risk pathways for sea-based and saltwater pond-based fish culture industries are also posed via introductions of marine ornamentals.

Table 2.4. 1. An example of marine pests which have relevance for aquaculture in Northern Australia. Adapted from (http://www.marinepests.gov.au/pests/map) and Queensland marine pest and disease guide/ Western Australian prevention list for introduced marine pests, Australia marine pest monitoring guideline.

Common name	Species	Potential entry point	NT	QLD	WA	NMS
Asian green mussel	*Perna viridis*	Vessels	+	/	+	Yes
Black striped mussel	*Mytilopsis sallei*	Biofouling on vessels	+	+	+	Yes
Asian bag mussel	*Musculista senhousia*	Vessels		+	-	Yes
Asian shore crab	*Hemigrapsus sanguineus*	Vessels	-	+	+	Yes
Brown mussel	*Perna perna*	Vessels	-	+	+	Yes
Asian basket clam	*Corbula potamocorbula*	Vessels	-	+	+	Yes
American slipper limpet	*Crepidula fornicata*	Vessels, translocation with oysters	+	+	+	Yes
Chinese mitten crab	*Eriocheir sinesnsis*	Fisher movement of live crabs	-	+	+	Yes
Asian paddle crab	*Charybdis japonica*	Biofouling on vessels, equipment	-	+	+	Yes
Harris mud crab	*Rhithropanopeus harissii*	Vessels	-	+	-	Yes
Rapa whelk	*Rapana venosa*	Vessels	-	+	+	Yes
Long necked calm	*Mya japonica*	Biofouling on vessels, fishers	-	+	+	-
Japanese Seaweed	*Unadaria pinnattifida*	Vessels	-	+	-	Yes

+ = Exotic and no incursion recorded in jurisdiction

/ = Detected in jurisdiction, but not considered exotic

* = Incursion recorded in jurisdiction or endemic

- = Not recorded on jurisdiction watch list

NMS National Monitoring scheme – species list compiled by NIMPCG Australia marine pest monitoring guideline

Table 2.4. 2 An example of marine disease that may have relevance for aquaculture in northern Australia. Adapted from Queensland marine pest and disease guide

Disease	Host species	Potential vector
White spot (WSSV)	Crustaceans, marine worms	Raw imported prawns as bait
Taura syndrome (TV)	Prawns, mud crabs	Raw imported prawns as bait
Yellowhead disease (YHV1)	Prawns, freshwater shrimp	Raw imported prawns as bait
Acute hepatopancreatic necrosis (AHPND)	Prawns, marine worms	Raw imported prawns as bait
Megalocytivirus (ISKNV, RSIV)	Marine and freshwater fish	Imported ornamental fish
Enteric septicaemia	Barramundi, catfish	Imported ornamental fish, wild fish
Viral haemorrhagic septicaemia (VHS)	Marine, freshwater fish, eels	Imported ornamental fish
Epizootic ulcerative syndrome (EUS)	Marine and freshwater fish	Translocation of fish
Acute viral necrosis of scallops (AVNV)	Scallops, clams	Imported molluscs as bait
Perkinsus olseni	Oysters, abalone, clams	Molluscs as bait, stock translocation
Scale drop	Barramundi	Imported frozen product used as bait

The list of pests and diseases listed in Table 2.4. 1 and Table 2.4. 2 are not definitive of all pests and disease. The National Introduced Marine Pest information System (NIMPIS) is scientific database of marine pests which details 100 marine pests that fit the criteria that they could be introduced in the future, are already in Australian waters or are native to some location but a pest in others.

Significant biosecurity risk is also posed by translocation of fish stocks infected with endemic pathogens into naïve cultured populations, and this poses risk to both land-based and sea-based culture operations. The greatest translocation risks are typically considered via the introduction of non-native species (Government of Western Australia, 2019), however translocation of infected 'conspecifics' across aquaculture enterprises also poses significant risk (State of Queensland, 2017). Stock within an enterprise are less likely to be screened prior to translocation to other locations on the farm due to operational practicalities and financial pressures which may trump biosecurity decisions at the enterprise level; and certainly, jurisdictions have diseases of national and international importance that are not listed on 'Declared Disease Lists' due to their known presence within the jurisdiction, and for which freedom must be certified if translocating to certain restricted areas (e.g. State of Queensland, 2011a,b).

The greatest biosecurity risk for land-based crustacean farming is also pathogen-borne diseases. For the largest of these industries operating in saltwater, the black tiger prawn farming industry, significant risks are posed by both exotic and endemic pathogens. Currently, only two of the multitude of exotic pathogens are routinely tested for by AQIS in uncooked prawn products entering the country (WSSV, YHV1; Inspector General of Biosecurity 2017), which contrast the many emerging pathogen risks which have emerged since the 2009 IRA (APFA, 2017). The key risk exposing many potential pathways for entry of these pathogens into the culture systems is via infectious 'prawn' products (or for WSSV, other crustacean products) passing through quarantine border checks and entering retail outlets. From here, a network of pathways can see the infectious products enter natural waterways as discards following consumption, bait, or berley, and subsequently enter aquaculture operations via water intakes, contaminated equipment or staff, and via other routes. On initial breach, outbreaks can rapidly spread, and particularly so across farms situated in proximity, even if farms do maintain the high practical levels of enterprise-level biosecurity. As was the case during the WSSV incursion in South East Queensland in 2016/17, where many farms maintained the highest practical levels of biosecurity possible at the time, including some of the later-impacted farms having ceased water intake into their farms for significant periods prior to experiencing WSSV impacts, disease can spread through vectors such as birds eating the dead and moribund animals that lie on the pond edges, before, carrying, defaecating and dropping infectious faeces or prawns into neighbouring sites and ponds (Sub-Committee on Aquatic Animal Health, 2016b; Brenta 2017; Diggles, 2017). Importantly, there is a long-list of other exotic pathogens (OIE list) which also pose high risk.

Significant biosecurity risk is also posed by translocation of marine prawn stocks infected with endemic pathogens into naïve cultured populations. A common example of such translocation risk would be the transfer of wild-caught broodstock from one region or jurisdiction to a hatchery and farming area in another region or jurisdiction (Brenta, 2017). In Queensland, the State with the largest prawn aquaculture industry, there is now a mandatory requirement of Biosecurity Queensland for NATA-accredited laboratory PCR testing of all individual wild caught and early generation domesticated broodstock being translocated into or within Queensland for WSSV, YHV1 and the PIR A/B toxin genes associated with both AHPND and PMMS (Penaeus monodon mortality syndrome); however as yet there is no such requirements for most endemic pathogens (State Of Queensland, 2018). Notably, the pathogen testing and general biosecurity requirements for wild-caught and domesticated broodstock and postlarval translocations into and within states do vary across jurisdictions, typically having the same broad aims, but with some differences in specific protocols (e.g. State of Queensland 2018, NSW Government Department of Primary Industries 2019). Across Australian jurisdictions, there is only limited regulatory requirement for screening of endemic pathogens (e.g. Yellowhead Virus 7; NSW Government Department of Primary Industries 2019) with more focus on evidence of disease rather than pathogen presence. Notably, the inability for regulators to require freedom from any of the endemic pathogens is grounded in the ongoing reliance on wild-caught broodstock for commercial production, which harbour these pathogens at variable but uncontrollable levels. While these endemic pathogens are not typically as virulent as the many exotic pathogens, significant commercial losses in terms of poor survival, growth and product quality have been attributed to endemic pathogens and their actual impacts have been largely ignored and poorly quantified through any R&D to date (Spann et al. 2000; Walker and Mohan 2009; Sellars et al, 2018; Jerry, pers. ob.). Importantly, the risk presented here is for both known endemic pathogens and for pathogens species or strains yet to be identified.

Freshwater-based crustaceans are also at risk from exotic and endemic pathogens entering farming systems. The redclaw crayfish (*Cherax quadricarinatus*) is the most valuable freshwater crustacean species cultured, and currently a likely candidate for future aquaculture expansion in northern Australia (Irvin et al, 2018). The knowledge-base of pathogens posing risk to this species is even more limited than for marine prawns (Saoud et al, 2013); however, the risk pathways associated with disease spread are consistent with many previously discussed. Notably, there is potential that invasive exotic or endemic pest species introduced into the natural waterways proximal to farming areas could impact redclaw crayfish populations within their natural NT and QLD range. However, this species currently seems more of a cause for biosecurity concern in the natural environment as it spreads into non-endemic areas in WA and NSW where it outcompetes native crayfish species (*Cherax* spp.) and marron (*Cherax tenuimanus*) (Government of Western Australia, 2015).

The greatest pathways posing risk to northern Australian aquaculture are posed by exotic pathogen introductions, and endemic pathogens translocated and spreading to naïve cultured populations. While there are many and intersecting pathways that can contribute to the exotic pathogen risk, the primary entry point of concern is via infectious products, primarily other exotic raw cultured or fishery products destined for human consumption, that pass through our quarantine systems and are subsequently used for alternative purposes that lead to infection of natural waterways and ecosystems. For endemic and emerging pathogens within the natural and farming systems of northern Australia, the primary concern is the movement of infectious broodstock or seedstock which can directly infect naïve culture populations in alternative localities and jurisdictions. For this latter risk, there is currently limited regulatory requirement or ability to mitigate this risk, and so such risks are best mitigated by industry operators being proactive in testing for endemic pathogens in the broodstock and seedstock they use in their operations.

2.5. Stakeholder Perceptions of Biosecurity

A recent survey commissioned by Animal Health Australia (AHA) in 2018 was undertaken to gauge the levels of understanding of attitudes towards, and views on responsibilities for, biosecurity and the biosecurity system, by aquaculture stakeholders;

this stakeholder group largely dividing into aquaculture farmers and other stakeholders (Mercer et al. 2018).

The survey found increasing awareness of biosecurity and its importance. However, perceptions of responsibilities for biosecurity (i.e. Federal government, State Governments, everyone) varied considerably, as did opinions on how effective the current biosecurity system is, and views on the nature of the key benefits of biosecurity (i.e. livelihoods, industry, environment). The survey revealed most farms are actively engaged in biosecurity, having biosecurity plans, keeping comprehensive records and employing biosecurity protocols, and undertaking various passive surveillance activities to mitigate disease risks. A significant number of farmers indicated they would seek support of diagnostic laboratories or health experts in the event of a suspected disease event, and most farmers would notify authorities immediately on suspicion of a major disease outbreak.

Two key recommendations of the survey's authors were (1) that despite increasing awareness of biosecurity among stakeholders, that education about Australia's approach to biosecurity needs to be increased and farms need to better understand and accept their roles, and (2) the need for improved awareness in identifying symptoms of notifiable diseases, and regarding actions to be taken and key governmental contacts in the event of a suspected notifiable disease episode.

Of most concern, the survey revealed that most stakeholders, both farmers and other stakeholders alike, considered the likelihood of a major outbreak in the next year (most likely from viral or bacterial diseases) as likely, or very likely.

2.6. Strengthening Biosecurity for Northern Australian Aquaculture

In the last decade most biosecurity outbreaks in Australia have occurred in the north (Commonwealth of Australia, 2015). Increasing numbers of agriculture operations in this region, coupled with increased farming intensification and other megatrends of increased trade and climate change, will increase exposure and likelihood of incursions of exotic pests and disease. The federal government has recognised that northern Australia has an environment that faces different risks to other parts of Australia due to its proximity to other countries and the tropical environment that is more receptive to certain pests and diseases (Commonwealth of Australia, 2015). There is need for ongoing vigilance and strengthening of the biosecurity system for the future sustainability and development of the aquaculture industries in northern Australia; and certainly, there is well established knowledge that biosecurity is more effectively managed through prevention than response (Roberts et al. 2013, Commonwealth of Australia, 2015). The requirements of the biosecurity system that protect aquaculture industries will need to fit with the wider biosecurity system that protects natural environments, human health and other agricultural industries. The investment made in ensuring aquaculture biosecurity in northern Australia will be dependent on the scale of industry development planned and achieved, and the degree of biosecurity risk posed. Importantly, priorities for investments in biosecurity will need to be made and justified on perceived benefits to the aquaculture industry and the wider community. Multiple reviews and reports commissioned or produced by industry and governmental agencies have identified key areas critical for improving biosecurity in northern Australia. The following section discusses the key knowledge gaps identified, recommendations made, and pose the future opportunities for strengthening biosecurity for the northern Australian aquaculture industries.

2.6.1. Pre-border testing and the ALOP standard

The framework for mitigating biosecurity breaches associated with pathogen-infected products, typically seafood and live-animals operate to the ALOP (Appropriate Level of Protection) standard. For Australian aquaculture, the ALOP for exotic pathogens is prevention through a range of offshore measures (Interim Inspector-General of Biosecurity 2012; Inspector-General of Biosecurity 2017; Commonwealth of Australia, 2016) coupled with 'at-the-border' surveillance of imports of raw seafood products. Importantly the Australian Government biosecurity measures to maintain ALOP aim to reduce risk to a very low level, but not zero. For imported prawn products, only two viral pathogens, of the many potential exotic pathogens, are routinely tested for in uncooked prawn products by AQIS (White Spot Syndrome Virus- WSSV and Yellow Head Virus 1 – YHV1; Inspector General of Biosecurity, 2017). For imported raw finfish and mollusc products, while subject to specific restrictions, there is no testing for exotic pathogens of concern to Australian aquaculture producers. Recent comments from the Inspector-General of Biosecurity affirm that current NAQS policy on the import of raw seafood products fail to meet the Australian Governments objective on ALOP (Inspector General of Biosecurity, 2017). But due to the complexity of this issue in relation to international trade, and costs of exhaustive pathogen surveillance, it is unlikely that zero risk could ever be achieved or that all key stakeholders would ever fully-accept any ALOP standard that does not work towards zero risk. To this end, the APFA has recommended that the IRA should not be based on 'disease testing' as this can never achieve zero risk for known tested pathogens, let alone the unknown pathogen risk (APFA, 2017). Currently review of the ALOP standard for imported prawns is underway (Australian Government, Department of Agriculture, 2019). The 2017 senate inquiry of the biosecurity risks of seafood products made several recommendations to strengthen offshore biosecurity (Commonwealth of Australia, 2017). Broadened testing of imported uncooked prawn products for exotic pathogens on the OIE list would likely strengthen biosecurity, but would come at significant cost, yet still not ensure zero risk.

2.6.2. Within-border surveillance

Australia operates a 'passive' surveillance system for early detection of pathogens, which is used to meet international reporting requirements and provides the information to demonstrate freedom from specific exotic aquatic diseases. This system is supported by measures to increase recognition of disease and legal requirements to report notifiable diseases of significant mortality events, and a national system to collate information on disease occurrence (AQUAPLAN 2014-2019). This within border pathogen surveillance system aids management of endemic pathogen spread and informs on translocation policies and identifies exotic pathogen breaches. Surveillance programs focused on ballast and biofouling issues of maritime shipping are in place and will remain important to stem the exotic pathogen pathways originating from exotic pest species incursions in coastal waterways. Enhanced understanding of the distribution of pathogens is critical for enhancing biosecurity as live stocks and products are transported across jurisdictions and farming operations.

Pathogen prevalence and loadings in populations vary over time, and long-term surveillance 'programs' that operate on an ongoing basis for the known list of endemic pathogens are required to understand pathogen distribution over time. Recent submissions regarding the IRA from the APFA have listed increased within border surveillance as an industry priority (APFA, 2017). Research to understand the geographic distribution of endemic pathogens across farmed and wild populations for aquaculture species of northern Australia is limited (Humphrey et al. 1998, Jerry et al. 2010, Cowley et al. 2015, Lymbery et al. 2016). Importantly, programs comprehensively monitoring pathogens over time and across the full range of farmed and wild populations, which is akin to 'environmental biosecurity' surveillance, are typically considered as too expensive for government to implement (Parliament of Australia, 2015). While the federal government has acknowledged the need for investing in the 'right' research, development and extension activities, they have also articulated the need to address 'gaps in the biosecurity system' via improvements in collaboration, adoption, and the overall efficiency of the system (Commonwealth of Australia, 2015). Consequently, alternative approaches that are integrated with industry regulatory requirements or operational research projects may provide a cost-effective alternative. Such approaches are consistent with surveillance approaches that underpin the plant agricultural industries where environmental biosecurity is largely achieved via surveillance done in association with the industry sector (Roberts, 2013).

For northern aquaculture though, in particular, there is significant R&D investment required to understand the occurrence, distribution, and importantly impact of endemic pathogens, so that they can be more effectively excluded or managed by industry to limit their impacts.

2.6.3. Aquatic animal health and biosecurity capabilities

Of critical importance for aquaculture biosecurity are the systems and capabilities for pathogen surveillance, rapid diagnosis, emergency response and recovery response. Such capabilities are critical for at-the-border testing, but there is even greater need in the regions to support the requirements for within border surveillance, industry operational management and emergency response. While AQIS has well established capacities and arrangements for the current requirements of testing at-the-border, the capabilities for the within-border roles, and certainly the qualified staff able to undertake these roles, across the northern jurisdictions is limited. The Queensland government's closure of the Oonoonba laboratories was considered a poor decision by some and has resulted in the northern aquaculture industries having to send samples to southern Queensland where the laboratories have often struggled to meet demands and critical timelines for diagnoses and response (Commonwealth of Australia, 2016b). As is the case for biosecurity needs for other agriculture industries in northern Australia, there is a lack of regionally employed front line staff trained in all areas of aquatic animal health that can respond to outbreaks on-the-ground and in real time (Commonwealth of Australia 2015, 2016b). Moreover, need for funding assistance for the establishment of a pest and disease diagnosis facility in Northern Queensland has been identified which again can provide both the capacity but also the timeliness of diagnosis and response; though there is acknowledgement that costs of such facilities make it unlikely that multiple laboratories would operate in each region/jurisdiction in northern Australia (Commonwealth of Australia, 2016b).

Fundamental to improving biosecurity prevention and response is the improvement in human capacity in terms of education, skills and training. There is a dearth of qualified professionals trained in aquatic animal health globally, and certainly this is also the case in Australian and particularly the north (JCU in Commonwealth of Australia, 2016b). Increased numbers of professionals qualified in diagnostics and related laboratory health services, but also in 'on-the-ground' emergency response, are required. Epidemiological expertise is required to understand the risk pathways and develop appropriate strategies and policies to mitigate exotic and endemic pathogen risks. Such expertise will take time to develop, and there will be competition for the human capital with other areas attractive to qualified staff. The need to address the aquatic animal health expertise deficit is longstanding, with recommendations for preparation of a curriculum in 'Aquatic Animal Health' identified since 2015, as was the need for a proper training facility and for coordination of this training capacity at the national level (AQUAPLAN 2014-2019, Sub-Committee on Aquatic Animal Health, 2016a). However, no substantive progress appears to have been made. Moreover, the importance of ensuring that aquatic animal capabilities are not forgotten in any future strengthening of first response capabilities across the primary industries was highlighted in AQUAPLAN 2014-2019.

The government laboratories in each jurisdiction fulfil a range of mandatory roles attendant to biosecurity, but concerns over the scope of the roles undertaken, and the turnaround times for results coming from these laboratories, have been raised. Until recently, there was no non-government NATA accredited laboratories in northern Australia (with JCU AquaPath currently being the only non-government lab), which was viewed as a significant constraint for industry efforts to enhance biosecurity. Some sections of industry also consider the inability to undertake routine 'testing' of key exotic pathogens, and the inability to use 'test kits' available internationally to screen for such pathogens, as a key constraint to their biosecurity efforts. New diagnostic tests are emerging and there is ongoing need to validate these tests for suitability for intended purposes and to validate against OIE tests. But notably, the suitability of some of the current OIE tests for purposes has even been raised; this highlighting the importance of ongoing validation of all tests being used by Australian diagnostic laboratories (AQUAPLAN 2014-2019). All considered, the further building of diagnostic capacity, and particularly the development of rapid turnaround diagnostic capacity for endemic pathogens, is widely viewed as critical for developing the northern Australian aquaculture industry.

One proposed solution to the constraints of biosecurity capabilities for northern Australian agriculture industries is to locate a pest and disease diagnosis and challenge facility within a university campus providing proximity to a broad range of health and diagnostic expertise (Commonwealth of Australia, 2016b). James Cook University has been identified as a hub for aquaculture research training (Commonwealth of Australia, 2016b) and it would seem appropriate to couple this with related training in aquatic aquaculture health relevant to the northern aquaculture industries. The inclusion of pathogen challenge capacity within this research hub, within an appropriate containment facility, would significantly enhance both general disease diagnostic capabilities, and aquatic animal health educational capacities, for northern Australia.

Beyond detection, surveillance and eradication, the capability to return to operations following a disease emergency is crucial to the continued expansion of aquaculture in northern Australia. Access to registered veterinary chemicals and treatments following the establishment of an industry disrupting pathogen is particularly poor. For the finfish aquaculture industries, whilst vaccines against bacterial diseases have the potential to be rapidly developed, the absence or inability to rapidly roll out emergency vaccines against viral pathogens poses the most significant threat. Whilst vaccines are able to be engineered for some viruses, particularly those affecting the salmon industry where considerable research investment has occurred in Europe and North America, a similar level of technical knowledge on viruses that affect tropical species is not available to support a rapid roll out of an experimental vaccine. For the oyster and prawn industries, there is an absence of any effective treatment to infection by viruses. The lack of preparedness is particularly high risk as the lead in time for the registration of chemicals and treatments within the biosecurity requirements of DAWR and the demonstration of efficacy and safety of use for the scope of application within APVMA is significant. Industry may need to be able to withstand successive mass crop failures over the duration required to develop treatments. Where chemicals are approved for response/recovery activities, there can be significant logistical barriers to rapidly access large volumes in Northern Australia. Future developments of treatments for tropical aquaculture species, and the supporting systems to enable such treatments to reach the farms following disease episodes, will be critical for the long-term development and expansion of the aquaculture in northern Australia.

2.6.4. Domestication and breeding of high health lines

For those industries which currently rely on wild-caught broodstock to supply seedstock for commercial farming, such as the prawn industry, the development of domesticated and selectively bred lines of 'known' and 'high health or Specific Pathogen Free (SPF)' status would be game changing in terms of mitigating risks from both endemic and exotic pathogens. The development of breeding programs to supply domesticated, high health and genetically elite seedstock for commercial farming has been a longstanding priority for the barramundi and prawn farming industries (APFA, 2015, pers. comms. Dick 2019). To date, many initiatives to start and develop such breeding programs have failed to have widespread and long lasting impacts across industry. While challenging and requiring of significant investment, the future success of such breeding programs would overcome what is arguably the greatest biosecurity risk to those industries currently relying on wild caught broodstock. Industry investment and governmental supports to foster development of such programs, and encouragements for a 'whole of industry' switch to high health stocks, would be invaluable for future development and expansion of northern Australian aquaculture.

2.6.5. Enterprise-level Biosecurity Planning

Improved biosecurity planning at the individual enterprise level is also fundamental to mitigating risk and containing endemic disease issues within the farming operation (AQUAPLAN 2014-2019). Certainly, there is always need to move live aquatic animals for production, genetic improvement or human consumption needs, which inevitably increases risk of disease contagion. Risks of disease can be mitigated by careful operational management, or by industry or enterprise level agreements for using animals only 'free' of pathogens of concern (AQUAPLAN 2014-2019). To assist in mitigating biosecurity risks at the enterprise and industry level, and facilitate interjurisdictional translocation and trade, AQUAPLAN 2014-2019 proposed to develop, with involvements of key stakeholders, a model for an enterprise-level health accreditation scheme that meets international standards and is agreed by states and territories.

There have also been efforts to develop an aquatic deed, which would involve aquatic industries and governments working together to develop a formalised government and industry cost sharing arrangements in respect to aquatic emergency animal disease response (EADRA) (Animal Health Australia, 2019). However, many concerns raised have prevented development of such an aquatic deed that could both assist in managing and supporting the aquaculture industries in emerging disease incursions (Parliament of Australia, 2017).

2.6.6. Increasing R&D and resourcing

Australia has a unique and poorly understood range of endemic aquatic pathogens (Sub-Committee on Aquatic Animal Health, 2016a). Research has a critical role to play for the northern aquaculture industry in increasing knowledge of disease agents and their epidemiology, with a good example in the pearl industry being the call for a taskforce to research the causative agent of OOD (Commonwealth of Australia 2016). The FRDC Sub-Committee on Aquatic Animal Health has been, and continues to be, the most significant public funder of research underpinning the health and biosecurity concerns of the Australian aquaculture industry, with a broad research scope including understanding disease epidemiology, biosecurity, diagnostic methodologies and new technologies, surveillance, disease mitigation and training (Sub-Committee on Aquatic Animal Health, 2016a). But due to relatively large number of species that are cultured, the even larger number of pathogens presenting, and the relative infancy of aquaculture as compared to terrestrial livestock industries, the challenge of developing a strong knowledge-base to support industry remains significant.

Long term surveillance of endemic pathogens of cultured species is essential to understand the ongoing risks. However, relatively few projects have focused on within-border surveillance and gaining a broader understanding of aquaculture pathogens in the context of improving biosecurity for northern Australian aquaculture industries (Humphrey et al. 1998, Jerry et at. 2010, Cowley et al. 2015, Lymbery et al. 2016). Research to identify 'new' endemic and emerging pathogens that are causing disease in farming populations, and to understand the epidemiology of harmful pathogens, is also important to future manage biosecurity and inform translocation policies. Certainly, the FRDC Sub-Committee has been the primary funder of such research (e.g. Sub-Committee on Aquatic Animal Health, 2015, 2016c, 2017), and the contributions of this research has been important for the northern Aquaculture industries. Notably, a current project focused on the prawn farming sector, and funded through the FRDC and the CRCNA, is undertaking pathogen surveillance and epidemiology in relation to biosecurity incidents within the industry (Jerry 2018).

More recently, the need to increase biosecurity related research resourcing to underpin aquaculture development in northern Australia has been recognised and suggested through a northern node of the Fisheries Research and Development Corporation (FRDC) (Commonwealth of Australia, 2016b) and potentially through the present CRCNA. Future strengthening of the biosecurity system to support development of the northern Australian aquaculture industry will need to be grounded in a strong knowledge-base stemming from quality research.

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APPENDIX

1. THE BIOSECURITY SYSTEM

1.1 BIOSECURITY SYSTEM FORMATION

The Department of Agriculture and Water Resources (DAWR) has primary responsibility for managing Australian biosecurity. The Department assesses unmanaged risk to determine if measures are required to reduce the risk to an acceptable level. The department considers International guidelines and standards such as the World Trade Organisation, World Organisation for Animal Health (OIE), International Plant Protection (IPPC), Codex Alimentarius (Codex) and considers additional measures that support Australian biosecurity needs. The Australian Government implements biosecurity measures to maintain an appropriate level of protection (ALOP). ALOP as expressed in the Biosecurity Act 2015 is a high level of sanitary and phytosanitary protection aimed at reducing risk to very low level, but not zero.

An incursion in Darwin harbour (black-striped mussel) in the late 1990's necessitated the formation of a National Taskforce, which recommended long term reform of marine biosecurity, culminating in the establishment of the National System for the Prevention and Management of Marine Pest Incursions in 1999 (the National system). A National Introduced Marine Pests Coordination Group (NIMPCG) was formed to develop reform measures under the National system. The NIMPCG was chaired by DAWR with representation from Australian, State and Northern Territory Government, marine industries, scientists and environmental organisations.

In 2002 the National system developed the Intergovernmental Agreement on a National System for the Prevention and Management of Marine Pests (Marine Pest IGA) with a focus on incursion prevention, emergency response, management and control of established pests (Commonwealth of Australia, 2005). The Marine Pest IGA did not come in to effect, though some parties (signatories to the agreement) did agree to develop and implement the described measures.

Up until 2016, the primary Commonwealth legislation covering marine biosecurity was the *Quarantine Act 1908*. This was repealed by the *Biosecurity Act 2015* which is administered by DAWR. The Department of the Environment (DE) administer the *EPBC Act 1999* which is the key Commonwealth environmental legislation. In administration of *Biosecurity Act 2015* DAWR and DE utilise policy input from multiple government agencies.

1.2 BIOSECURITY REGULATION BY NORTHERN AUSTRALIA JURISDICTION

Management of pest and pathogen species across Australia is complex due to regulation by various State, Territory and Federal legislation. Each jurisdiction may have their own legislation and strategies for managing pest species and pathogens consistent with their constitutional responsibilities. A key committee is the Marine Pest Sectoral Committee (MPSC) comprised of two representatives from the Australian Government and one from each jurisdiction and three independent observers with technical or scientific expertise. The role of the MPSC is to coordinate the implementation of national measures to identify, minimise and address the pest risk to Australia's environment and associated industries and in an advocacy role within Government highlighting the impact pests can have on environment and industry.

Under Australian Constitution, pest management is the responsibility of the jurisdictions. The jurisdictions may legislate specific responsibilities and endorse codes of practice and standard operating procedures or guidelines. The Northern Territory, Queensland and Western Australian Government are all signatories to the Intergovernmental Agreement on Biosecurity, a commitment to national biosecurity management (COAG 2012a).

1.2.1. Northern Territory

The Northern Territory Governments Biosecurity strategy 2016-2026 is aligned with the Intergovernmental Agreement on Biosecurity. The *Commonwealth Biosecurity Act 2015* is the primary piece of national legislation, co-administered by the Ministers for DAWR and Health. In the Northern Territory the Department of Primary Industry and Fisheries and the Department of Land and Resource Management play the primary roles in the biosecurity management of pests and disease. The parks and wildlife commission are responsible for marine protected areas in the Territory. The Northern Territory has an Aquatic Biosecurity unit that monitors and manages risk of marine pest arrival in the Territory. The Northern Territory does not have a biosecurity specific Act.

1.2.2. Western Australia

The *Biosecurity and Management Act 2007* (BAM Act) is the principal legislation administered by the Department of Agriculture and Food Western Australia (DAFWA) for biosecurity management. The BAM act came in to effect in 2013 replacing 16 older Acts and 27 regulations with one act and nine regulations. The Biosecurity Council of Western Australia (assembled under the BAM act) advises the Minister and DAFWA on biosecurity policy. Community reporting of potential biosecurity breach is via the Pest and Disease Information Service (PaDIS) an arm of DAFWA. The Western Australian organism list (WAOL) provides status of organisms as classified by the BAM Act. The status of an organism determines whether a permit is required to import the organism into Western Australia, whether products (possible carriers) possibly infected with the organism need to satisfy any import conditions into Western Australia. Unlisted organisms require a permit for import. Recognised Biosecurity Groups (RBG's) have been established and are formally recognised under BAM act to control and biosecurity risks by tenure, enabling landowners and managers coordinated approach in the area supported by the Biosecurity group guidance document.

1.2.3. Queensland

Biosecurity Queensland (BQ - Department of Agriculture, Fisheries and Forestry) is responsible for coordinating the response to introduced pests at the State-wide scale. BQ works with local government and landholders, who have the primary responsibility in the implementation of pest management planning. There are 14 regional Natural Resource Management (NRM) Groups, which support each region with advice assistance and programs. The *Biosecurity Act 2014 (commenced July 2016)* is the principal legislation administered by Biosecurity Queensland. Biosecurity Regulation 2016 describes how the Act is implemented and applied. The state Government is in the process of establishing a

Biosecurity Queensland Ministerial Advisory Committee (BQMAC) to provide strategic oversight and advise the Minister for Agricultural Industry Development and Fisheries around key biosecurity and support implementation of the Queensland Biosecurity Strategy 2018-2023.

In terms of cross jurisdictional activities, Interstate Deployment Arrangements provides guidance on the coordination and deployment of jurisdictional staff in a biosecurity response. (DAWR). The National biosecurity committee has agreed to principles to assess whether a pest or disease is of national significance and whether a nationally coordinated response is in the nation's interest.

1.2.4. Biosecurity at the Enterprise Level

Australia's biosecurity system is one of shared responsibility. Enterprise owners take responsibility for their own biosecurity, to protect the viability of their business. A farm that has effective on-farm biosecurity is more likely to be secure against known and unknown biosecurity risks which may enter Australia in the future. (Commonwealth of Australia, 2017). At the farm level there is an emphasis on self-regulation of industry biosecurity standards and protocols. In 2017, DAWR released a guide to assist develop biosecurity plans at the farm level. This guide is a generic template which can be adapted to suit the sector (e.g. prawns) and the production system (e.g. ponds).