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Growth opportunities and critical elements in the supply chain for wild fisheries and aquaculture in a changing climate

A Marine NARP Project

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FRDC Project No. 2011/233
February 2014

FRDC FISHERIES RESEARCH & DEVELOPMENT CORPORATION
IMAS INSTITUTE FOR MARINE AND ANTARCTIC STUDIES
UTAS
Australian Government
Department of Climate Change and Energy Efficiency

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The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

National Library of Australia Cataloguing-in-Publication entry

Author:	Hobday, Alistair J., author.
Title:	Growth opportunities & critical elements in the supply chain for wild fisheries & aquaculture in a changing climate. Final Report. FRDC-DCCEE Marine National Adaptation Program 2011/233. / Hobday, A. J., Bustamante, R. H., Farmery, A., Frusher, S., Green, B., Jennings, S., Lim-Camacho, L., Norman-Lopez, A., Pascoe, S., Pecl, G., Plaganyi, E., van Putten, E. I., Schrobback, P., Thebaud, O. & Thomas, L.
ISBN:	1-922173-57-7 (ebook)

Suggested citation

Hobday AJ, Bustamante RH, Farmery A, Fleming A, Frusher S, Green B, Jennings S, Lim-Camacho L, Norman-Lopez A, Pascoe S, Pecl G, Plagányi E, van Putten I, Schrobback P, Thebaud O and Thomas L (2014) Growth opportunities & critical elements in the supply chain for wild fisheries & aquaculture in a changing climate. Final Report. FRDC-DCCEE Marine National Adaptation Program 2011/233.

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1 Non technical summary

2011/233. Growth opportunities & critical elements in the value chain for wild fisheries & aquaculture in a changing climate

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OBJECTIVES:

1. Describe the current state of biology, fishery, policy and management of each case study fishery.
2. Develop supply chains for each of the selected fisheries, with biological, social and economic input.
3. Develop future models of these supply chains to identify opportunities and barriers with regard to environmental change, biology, social and economic factors.
4. Develop strategies to overcome the barriers and take advantage of the opportunities.

NON TECHNICAL SUMMARY:

OUTCOMES ACHIEVED TO DATE

The overall premise to this project is that adaptation by Australian fisheries and aquaculture sectors to climate change will be enhanced by increased awareness of markets and opportunities along the supply chain. The specific project outcomes were to (i) identify inefficiencies and potential points for enhancing profitability (ii) identification of strengths and weaknesses in the value chain, and together with the LCA, development of adaptation options, and (iii) development of realistic adaptation management and policy options to enhance cost-effectiveness along the supply chain. To date, current perceptions regarding the options for fisheries along the supply chain were determined, and used to guide development of adaptation options, based on the social perception studies (status quo interviews). Inefficiencies and potential points for enhancing profitability including targeted recommendations in relation to efficiencies and reduction of the carbon footprint were identified using life cycle assessment. Strengths and weaknesses in the chain were identified using critical element analysis and together with the LCA, informed the development of adaptation options. Economic analyses underpinned identification of influence of market factors on the price and profit options for selected sectors. Final interviews evaluated the potential responses and the acceptability of adaptation options for participants in the case studies. Overall, using these techniques, we have developed a set of approaches to generate realistic adaptation management and policy options to enhance "growth and opportunities" along the supply chain. These will directly benefit the adaptation efforts of the seven selected seafood sectors, and can be applied to additional sectors in future.

It is now apparent that climate change is impacting the oceans around Australia, in particular significant warming of ocean temperatures has been documented on both the east and west coasts. Such changes are in turn impacting coastal marine ecosystems by altering the distribution, growth, recruitment, and catch of exploited marine species, and as result, marine resource-based industries, such as fishing and aquaculture, are expected to see both opportunities and losses. Seafood industries may need to adjust practices in order to maintain or enhance production. This adjustment is important as seafood plays an important role in food and economic security and supplies about 10% of world human calorific intake, and is an important regional industry and employer in Australia.

The response of fisheries to climate change is an area of active investigation, however, the bio-physical elements of these industries have so far received the most attention. Long-term shifts in target species and fisher activity have been reported from Australia and many other countries, while climate-related extreme events such as floods and cyclones also impact fisheries and aquaculture. Planning responses to climate change relies on a solid biophysical understanding, yet this is not sufficient as the full range of opportunities and threats that will confront fisheries and aquaculture as a result of climate change are not just at the production end of fisheries. Consideration of the impacts of climate change along seafood supply chains, the steps a product takes from capture to consumer is vital to safeguard the ongoing supply of seafood.

> "a supply chain is the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer" (Christopher, 1992).

The overall premise to this project is that adaptation by Australian fisheries and aquaculture sectors to climate change will be enhanced by increased awareness of markets and opportunities along the supply chain. Accordingly, we developed supply chains for a set of seven fishery and aquaculture case studies: southern rock lobster (Tasmanian sector), tropical rock lobster (Torres Strait fishery), western rock lobster, Sydney rock oyster, wild banana prawns (NPF sector), aquaculture prawns, and Commonwealth trawl sector (CTS). These selected sectors allowed comparison between competing wild products (e.g. lobster fisheries), wild and aquaculture products (prawns), and domestic and international markets (e.g. lobster and CTS).

Fishery descriptions of seven case studies were completed (**Objective 1**), spanning wild fisheries and aquaculture, a range of taxa, and geographic regions**.** Supply chains for these case studies were generated, and enhanced with estimates of flow of product along different pathways **(Objective 2).** These supply chains were used to support a number of related analyses including life cycle assessment (LCA) which can underpin improvement in the use of resources along the supply chain. Such improvements may be increasingly important to consumers with increased climate awareness (e.g. carbon miles) and producers (e.g. carbon tax). Interviews with stakeholders generated insight into current awareness of important supply chain issues, while economic analyses showed from the markets end of supply chains, where links between seafood sectors may restrict the range of adaptation options. For example, where competing products (e.g. SRL and WRL) are seen as substitutes in the market, an adaptation strategy to reduce the catch of one species in order to boost price may not achieve the desired result. Greater coordination across the harvesting states may be an advantage, but acknowledge that no formal cost-benefit analysis of this formal coordination was conducted. A future research project could examine with the industry and states, how collaboration in the export market could be achieved, and the economic value realised by such an arrangement.

A new method was developed to assess the stability of supply chains and identify critical elements, and represents a significant advance in supply chain approaches. This method identified where efforts should be directed to make the whole supply chain more resilient.

Future scenarios and potential adaptation options were also identified (**Objective 3 and 4**). The specificity required for adaptation options required a small set of "general" options to be considered in the project. Two to three scenarios for each case study were considered, collectively representing three supply-driven changes (slow change in abundance, shock change in abundance, slow change in distribution) and three demand-driven changes (slow change in consumer preference, slow change in market/competition, or a market shock). These scenarios can result in increases and decreases in environmental performance across the supply change. As examples of scenarios and impacts on the supply chain, LCA for four of the case studies suggested that for:

- Southern rock lobster – changes in abundance and distribution are most likely to impact on the catch phase and hence global warming potential (GWP) of the supply chain. If reducing greenhouse gas emissions becomes important to consumers, the emissions generated in catch phase will need most attention.

- Wild prawns – a potential increase in availability of wild prawns may lower CPUE with some reduction in GWP at the catch phase, but in the longer term, increases in the export phases may increase the environmental footprint as assessed by the LCA indicators.
- Commonwealth trawl sector – long-term increases in efficiency may occur as a result of fleet and logistic movements southwards (following the fish), but an increased environmental footprint is expected in the short-term in response to these changing fish distributions.
- Tropical rock lobster - a decrease in the environmental footprint of the supply chain is expected from a change in the pathway to the export market (increased efficiency in transport)

Importantly, development of options to overcome barriers (**Objective 4)** should be undertaken in partnership with industry and managers, focusing on an agreed set of options and after defining "supply-chain" related objectives for each fishery. The tools and outputs from this project can also be used to undertake detailed exploration of trade-offs between different adaptation options.

The outputs arising from this project document the inefficiencies and potential points for enhancing profitability including recommendations in relation to efficiencies and reduction of the carbon footprint. Strengths and weaknesses in the chain were identified using critical element analysis and together with the LCA, informed the development of adaptation options. Economic analyses underpinned identification of influence of market factors on the price and profit options for selected sectors. A final set of stakeholder interviews evaluated the potential responses and the acceptability of adaptation options for participants in the case studies.

The potential impact of the research include the seafood sector stakeholders becoming more engaged in planning their future across the supply chain, and developing future strategies take advantage of opportunities identified in the LCA, critical metric and economic analyses. Development of these approaches to other seafood sectors will see improved outcomes for Australia in the face of a changing environment. Overall, we have developed a set of approaches to generate realistic adaptation management and policy options to enhance "growth and opportunities" along the supply chain. These will directly benefit the adaptation efforts of the seven selected seafood sectors, and can be applied to additional sectors in future. Future work, in partnership with industry experts at each stage of seafood supply chains, should be to consider the trade-offs in implementing each of the potential adaptation options in these cases studies and other seafood sectors.

KEYWORDS: Aquaculture, climate change, supply chains, fisheries, adaption options

2 Acknowledgments

We greatly appreciate the support and contribution to the outcomes of this project from fishery and aquaculture stakeholders from around Australia, for workshop participation, contributing data used in analyses, and participating in interviews.

This project was funded as part of the Marine National Adaptation Research Plan (NARP) funding package, to address the issues of fishery and aquaculture industry opportunities across the supply (or value) chain, in the face of changing environmental conditions in Australia and around the world, primarily as a result of climate change. Support and advice from Colin Creighton helped shape this final report.

3 Background

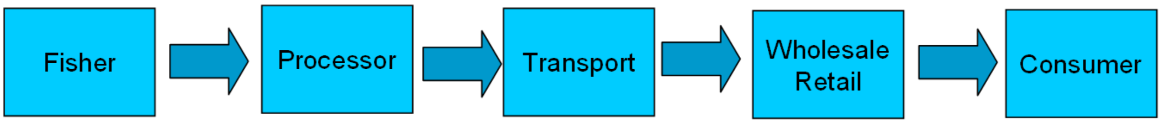
It is now apparent that climate change is impacting the oceans and is expected to increasingly do so into the future (Poloczanska et al. 2007; Hobday & Lough 2011). Significant warming of ocean temperatures has been documented on both the east and west coasts (Ridgway 2007; Pearce & Feng 2007; Lough & Hobday 2011). Such changes are in turn impacting coastal marine ecosystems (Ling et al. 2009; Last et al. 2011; Wernberg et al. 2011), by altering the distribution, growth, recruitment, and catch of exploited marine species, and/or their prey and predators (Poloczanska et al. 2007; Doney et al. 2012). As a result, marine resource-based industries, such as fishing and aquaculture, are expected to see both opportunities and losses (Hobday & Poloczanska 2010) and may need to adjust practices in order to maintain or enhance production. This adjustment is important as seafood plays an important role in food and economic security (Allison et al. 2009; ABARES 2011) and supplies about 10% of world human calorific intake (Nellemann et al. 2009; FAO 2011).

Thus, the response of regionally important marine industries such as fisheries to climate change is an area of active investigation, however, the bio-physical elements of these industries have so far received the most attention (e.g. Hobday 2010; Cheung et al. 2012). Long-term shifts in target species and fisher activity have been reported from around the world (e.g. Nye et al. 2009; Last et al. 2011; Pinsky & Fogarty 2012, Hamon et al. 2013), while climate-related extreme events also impact fisheries and aquaculture (Marshall et al. 2013; Wernberg et al. 2011; Caputi et al. 2010). Planning responses to climate change relies on a solid biophysical understanding, yet this alone is not sufficient as the full range of opportunities and threats that will confront fisheries and aquaculture as a result of climate change are not just at the production end of fisheries. Consideration of the impacts of climate change along seafood supply chains, the steps a product takes from capture to consumer (Peterson et al. 2000) is vital to safeguard the ongoing supply of seafood.

A supply chain is a schematic representation of the path that a product travels from, in the case of fisheries, capture to the consumer. A value chain is broadly defined as the value or feature added to the primary product by each level in the supply chain (**Box 1**). Added value to seafood products typically occurs in form of grading, filleting, packaging, cooling, storing and preparation for consumption, distribution and marketing by using labour and capital. Thus, each feature added to a product also adds cost items and profit margins to the final product value. During the early stages of the project, the difference between the scale of analysis and information required for value chain analyses compared to supply chain analyses became apparent and we continued to maintain a whole-sector analysis – hence a supply chain focus - rather than individual businesses within each sector – where a value chain focus would be appropriate.

Box 1. Supply chains and value chains

Supply chains are a representation of a system that transforms natural resources (e.g. wild fish) to a finished product (e.g. seafood) that is delivered to the consumer. We focused on developing supply chains for a range of fisheries, and supplement each chain with estimates of product flow along each branch of the chain. A supply chain for fisheries typically has at least 5 stages, as in the simple example below, and in this project, each supply chain had several pathways at each stage.



Value chains are supply chains with additional information - the economic value added at each level. Added value to seafood products typically occurs in form of grading, filleting, packaging, cooling, storing and preparation for consumption, distribution and marketing by using labour and capital. Thus, each feature added also adds cost items and profit margins to the final product value. The sum total of value-added at each level yields an estimate of total value. The example below is for an oyster value chain.

Supply chain	Oyster Grower	Interim transport	Primary wholesale	Secondary wholesale	Destination (Restaurant)	Domestic Consumer
Value & margin added / dozen:	Farm gate price	Freight: +$0.11	Oyster loss: +$0.15 Shucking: +$0.92 Packaging: +$0.10 Margin: +$1.65	Margin: +$1.32	Labour: +$3.03 Rent: +$0.55 Overhead: +$1.58 Net Margin: +$0.34	Meal price
Price / dozen	$5.00	-	$5.11	$7.93	$9.25	$14.75
Δ to farm gate price	-	-	+2%	+59%	+85%	+195%

Source: Based on estimations in Cominski (2009). Notes: estimations represent values for small bistro SRO sold by restaurant buffet in western Sydney, margins did not include provisions for overhead, delivery costs and other handling or management costs.

Value chains are closely linked to the concept of competitive advantages of firms which is used in business management. It is a tool that can be useful for individual business planning purposes as this method identifies cost drivers and point in the chain of supply where value is added. The value chain can be analysed to determine the economic consequences of changes of one industry on other industries, consumers, the economy and governments. Information for a value chain is often highly confidential, and in this project we did not attempt to gain this information, but used alternative economic tools to explore the economic consequences of impacts to the supply chain.

Examining supply chains is a useful construct for examining industries in their entirety, because the success of a chain relies more on the way components are assembled to provide effective delivery than on the components themselves (Peterson et al. 2000). A holistic perspective allows examination of barriers and opportunities that would not be apparent from a focus on a single element, such as the wild fish capture phase. Supply chains can range from complex representations that include all of the scientific, production, commercial, technical, structural, policy and related activities involved in the matching of the product to a consumer need, its production, storage, packaging, marketing, sale and transport, including in-chain and in-store quality management, to simpler, 3-stage fisher-processor-distributor representations (Peterson et al. 2000; Spencer & Kneebone2012). Improvements to supply chains have generally been based on an improvement in performance measures (**Box 2).**

Adaptation is the process of developing local responses to climate change and a deliberate change in anticipation of, or in reaction to, external stimuli and stress (Adger et al. 2005; Nelson et al. 2007). Adaptation can include both biological (e.g. changing distribution) and social adaptation (e.g. human responses such as fishers moving target locations or switching species) (Marshall et al. 2013). Catching fish is only the first step in the seafood industry. An understanding of how adaptation could occur along the post-harvest elements of the supply chain will complement existing bio-physical knowledge. To this end, documenting the potential impacts along the chain and the potential adaptation responses, coupled with integration of the social values or priorities showing which adaptations are favoured or limited could improve the effectiveness of adaptation. For example, public perceptions of seafood industries vary in terms of their sustainability, traceability, freshness, cost, and ease of preparation (Sparks 2011). While current perceptions of sustainability in seafood are primarily focused on proximate ecological concerns (e.g. eco-certification processes such as Marine Stewardship Council (Kaiser & Edward-Jones 2006), impacts stemming from the material and energetic demands of both industrial fisheries and aquaculture can also be substantial (Pelletier & Tyedmers 2008). For example, the capture and landing phase of wild marine fisheries account for about 1.2% of global oil consumption and directly emit more than 130 million tonne of CO_2 into the atmosphere each year (Tyedmers et al. 2005). Each step along the supply chain adds to the environmental burden and some products can travel thousands of kilometres before final consumption (Grescoe 2008; Merino et al. 2012). Improved energy efficiency and mitigation of emissions are therefore important parts of fisheries adaptation to climate change (Hobday & Poloczanska 2010).

As climate change impacts can propagate from the wild catch end of the chain, or impact directly on higher elements of the chain, opportunities for improvement and efficiencies, and adaptation may come in a range of elements of the chain. Thus, this project involves evaluating *growth opportunities* along the supply chain of representative Australian fisheries and aquaculture sectors, and identifying *critical elements* that are potentially vulnerable or unstable under a changing climate. We explain these terms as we have used them in this project:

<u>Growth Opportunity</u>: in the context of a changing climate, growth may be achieved through:

- increasing sustainable biological production – allowing, in the case of increased catches (perhaps as a result of higher fish recruitment or survival) a greater supply of product to market[1]. However, increased abundance of fish in the ocean does not always mean increased growth for a fishery, as a market must exist for the product.
- improving efficiency – decreased operating costs and increased profitability – thus growing the economic value. Common ways to achieve this include (i) increasing catch rates, (ii) by decreasing total allowable catches (TAC), or (iii) reducing competition for the same catch by reducing the number of vessels or licences. A decreased TAC often results in stocks increasing in biomass and thus further improvement to catch rates, however, a change in price may not always occur due to other market constraints.
- increasing value from existing production – value adding, or focussing on the more profitable markets or products, and reducing waste along the supply chain
- minimising vulnerability[2] and instability in the supply chain. This can be achieved by identifying critical elements (defined below) and internal vulnerabilities that can be addressed by industry or government actions.

Thus, in the context of a supply chain (in all other industries as well as fishing) growth is achieved by reducing costs, making things more efficient, value adding etc. We investigate these opportunities with a range of methods, as described in the body of the report.

1 Note that availability of biomass is not the main barrier for some fisheries - a willing and profitable market and delivery of a good product at a profit is the main issue. Some Australian fisheries have sustainable harvests above current levels, but no market, e.g. Australian salmon, school prawn. These are good products but Australian consumers appear to prefer white flesh fish and cheap prawns (e.g. imported from Asia).

2 Two types of vulnerabilities exist – those which you can manage (internal vulnerabilities – e.g. diversifying markets, vertically integrating company, minimising middlemen, catching own bait etc) and those which you cannot manage (external vulnerabilities – exchange rates, market failures (e.g. Server Acute Respiratory Syndrome, SARS), fuel prices etc). The growth opportunity is to minimise the internal vulnerabilities and increase resilience to the external ones, e.g. by at least considering options for diverse markets, alternative markets, alternate modes of export.

Critical elements: for this project these are links or nodes in the supply chain where:

- instability can occur (e.g. one broken link leads to major disruption)
- resource (plastics, carbon, fuel) use is particularly high – for example, the carbon footprint of a link or node

Critical elements in each of the supply chains are identified with Life cycle assessment and supply chain stability analysis, as described in the main report.

Box 2. How has supply chain performance been measured?

Supply chain performance improvement has been long hinged on initiatives that aim to match supply with demand, often on the basis of cost reductions while improving customer satisfaction (Christopher & Towill 2001). This is based on the philosophy that supply chains compete, not just individual companies (Christopher 1992).

There are several performance measures used against supply chains. From a logistics and functional perspective, the following have been widely used:

1. Balanced scorecard performance measures: financial, customer, internal business, and innovation and learning as they align with business strategy (Kaplan & Norton, 1992; Hendricks et al. 2009)
2. Performance prism: stakeholder satisfaction, strategies, processes, capabilities and stakeholder contribution (Neely et al. 2001)

Supply chain performance and its success have been largely based on quantitative measurements of cost, time and accuracy (Shaw et al. 2010). As such, improved supply chains, from this perspective, often relate to reduced costs, reduced time to market, and increased accuracy – all resulting to increased efficiency. This aligns with a long-standing performance criterion – the lean supply chain. The focus of the lean approach is the elimination of waste, stemming from the lean manufacturing concept in 1990s (Christopher & Towill 2001).

However, the lean supply chain became an inadequate definition of a high-performing supply chain when the realisation occurred that uncertainties in the chain are not addressed by the concept of being 'lean'. Agility has then been raised as a concept that addressees this gap. The principle behind the agile supply chain is the ability of a chain and its processes to respond and be flexible, enabling changes to product mix and volume (Christopher & Towill 2001). The concept of agility is seen to extend beyond the operational and logistical processes, moving into business mindsets, information and knowledge to manage and take advantage of market opportunities (Naylor et al. 1999).

Combining these concepts, a performing supply chain can then be defined as one that is able to meet market demand efficiently, with minimal waste, whilst maintaining an ability to respond to the needs and uncertainties of the internal and external environment.

In the context of this project, we seek to evaluate how supply chain performance can be improved to see fisheries and aquaculture businesses cope with climate related impacts for supply or demand for seafood.

4 Need

Climate change is impacting the oceans around Australia and is expected to increasingly do so into the future (Poloczanska et al. 2007; Hobday and Lough 2011). Information on environmental state and biological relationships to the environment, coupled with climate, ocean and management projections, allow qualitative projections of future stock trajectories (e.g. Brown et al. 2009).

The climate change research to date has focussed mostly on the biophysical relationship between known climate drivers like temperature, ocean currents, and the ecosystem. Very little assessment has been made to date at the intersection of climate change and the fisheries legislative framework and other marine planning and environmental legal instruments, or for the impacts of climate change along the supply chain.

Planning responses to climate change relies on a solid biophysical understanding, yet this alone is not sufficient as the full range of opportunities and threats that will confront fisheries and aquaculture as a result of climate change are not just at the production end of fisheries. Consideration of the impacts of climate change along seafood supply chains, the steps a product takes from capture to consumer (Peterson et al. 2000) is vital to safeguard the ongoing supply of seafood.

> *"a supply chain is the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer" (Christopher 1992)*

Whilst there may be negative impacts, there will also be opportunities for growth in some sectors, which may be prevented by inefficiencies in the supply chain, or by policies that do not enable opportunities to be realized. Thus, assessment across fishery supply chains could allow realisation of the potential benefits and minimise the losses for Australian fisheries as a result of climate change. Importantly, this will allow identification of elements within the supply chain where climate impacts can be reduced, and where policy can be developed to implement reduction measures. Analysis of the selected fisheries and aquaculture sectors across their supply chains, for social, economic and biological barriers and enablers will inform other fishery and aquaculture sectors.

The seven selected fisheries (see **Section 6)** represent a balance between wild harvest and aquaculture case studies, complimenting existing work (e.g. economic analyses of abalone and oyster[3] were being undertaken elsewhere), replicating species coverage in other marine NARP projects (e.g. southern, western and tropical rock lobster are in Pecl et al. FRDC 2011/039; Caputi et al. FRDC 2010/535 and Welch et al. FRDC 2010/565 respectively) to increase whole of system information for some species, representation of domestic and international markets, geographical coverage (tropical and temperate) and taxonomic diversity (finfish, crustaceans, molluscs).

[3] After the project commenced, we became aware of ongoing work on abalone and oyster, in particular economic analyses on oyster markets as part of a PhD project by Peggy Schrobback (QUT), and international abalone trade, by post-doctoral researcher Eriko Hoshino (UTas). Both these scientists were invited to join this project and have provided some results to guide this project, as reported in detail below.

5 Objectives

The objectives of this project were to:

1. Describe the current state of biology, fishery, policy and management of each case study fishery.
2. Develop supply chains for each of the selected fisheries, with biological, social and economic input.
3. Develop future models of these supply chains to identify opportunities and barriers with regard to environmental change, biology, social and economic factors.
4. Develop strategies to overcome the barriers and take advantage of the opportunities.

6 Methods

The project team has covered a total of seven fisheries and aquaculture sectors (**Table 1**). Initially, only five case studies were selected, but during the course of the project this number was expanded to the final seven. These selected sectors allowed comparison between competing wild products (e.g. lobster fisheries), wild and aquaculture products (prawns), and domestic and international markets. Not all analyses that we employed could be completed for all sectors, in particular, the intensive Life Cycle Assessment (LCA) was completed for four of the seven case studies, and the initial and final stakeholder interviews covered only the original five sectors, as the additional two sectors had not yet been agreed when this element of the project commenced.

Table 1 List of case studies included in the project and the analyses conducted for each sector. Economic analyses were conducted on multiple sectors at once

	SECTOR	FISHERY DESCRIPTION	SUPPLY CHAIN DEVELOPED	PRESENT ISSUES INTERVIEW	LCA	ECONOMIC ANALYSES	CRITICAL ELEMENT ANALYSIS	FUTURE SCENARIO INTERVIEW
1	Southern rock lobster, Tasmanian sector	Y	Y	Y	Y	Y	Y	Y
2	Tropical rock lobster	Y	Y	Y	Y	Y	Y	Y
3	Western rock lobster	Y	Y			Y	Y	
4	Sydney rock oyster	Y	Y	Y		*	Y	Y
5	Wild banana prawns	Y	Y	Y	Y	Y	Y	Y
6	Aquaculture prawns	Y	Y	Y		Y	Y	Y
7	Commonwealth trawl sector	Y	Y		Y		Y	

* Work already underway on this species – see Schrobback P, Pascoe S, Coglan L (in press) Market integration and demand analysis of the Australian edible oyster market. Aquaculture Economics & Management.

To achieve the project objectives, the project utilized a variety of methods, including perception analysis – involving interviews with stakeholders (social perception analysis), life cycle assessment of supply chains, critical element analysis (developed in this project), economic analysis (market integration and demand analysis), adaptation options, and scenario generation. These project methods, or elements, contributed to the project outcomes as described in the following schematic (**Figure 1**) and **Table 2**. These methodological elements are all linked; for example some information gained from constructing the supply chain is also used in the economic analyses, life cycle assessment, and critical element analysis. These in turn contribute to the development of plausible future scenarios and adaptation options (**Figure 1**). Each of these methods is summarised in the following sections and additional methods, results and discussion provided as part of manuscripts prepared for publication (see A**ppendix D**).

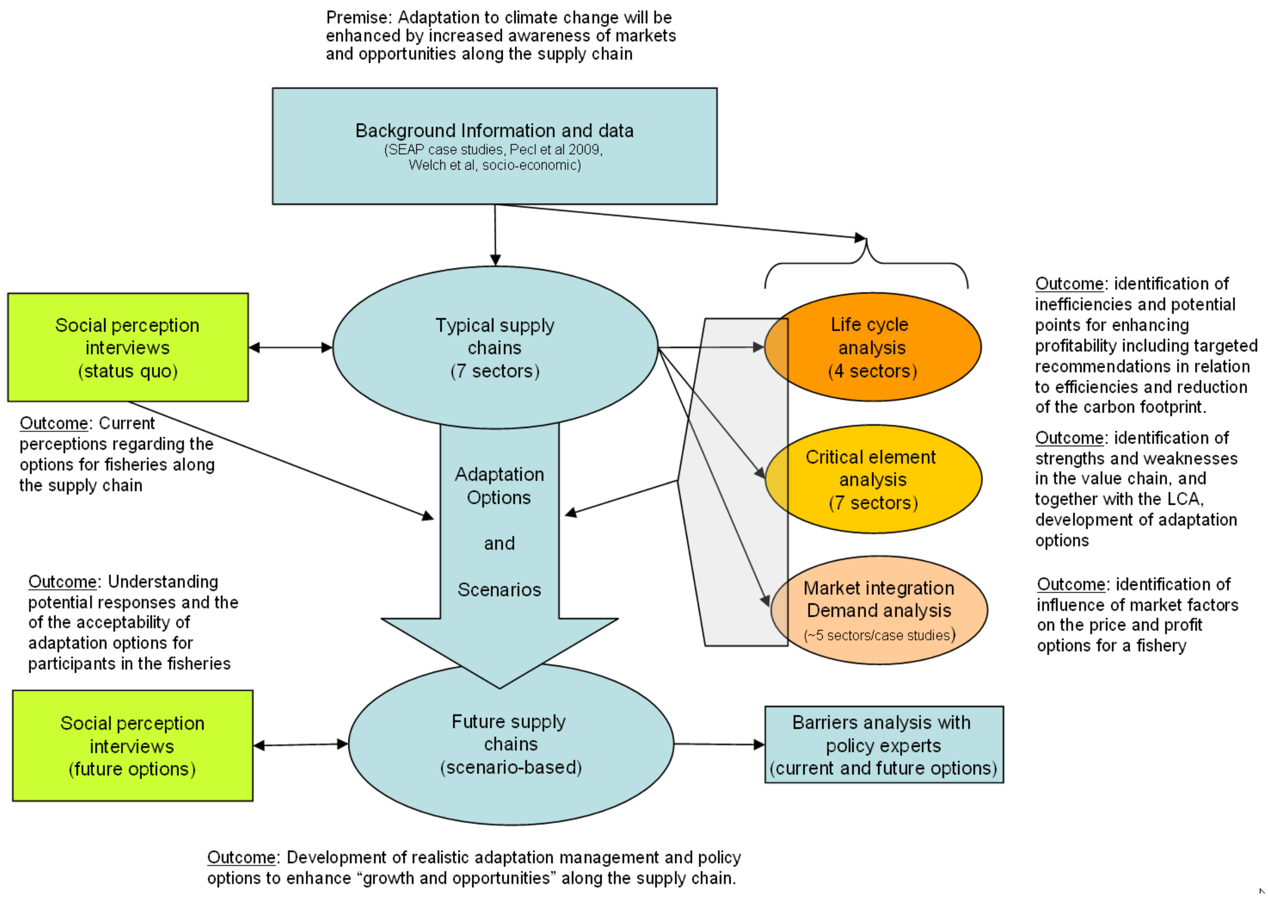


Figure 1 Project linkages and outcomes from each of the methods used to achieve the project objectives.

Table 2 Methods for each objective and formal outputs relevant to each objective. The papers submitted for publication often included results from status quo supply chains and future considerations, and hence span objectives.

	OBJECTIVE	METHODS	OUTPUT – BEYOND THE FINAL REPORT
1	Describe the current state of biology, fishery, policy and management of each case study fishery	Literature search and review of information in companion projects	Appendix C
2	Develop supply chains for each of the selected fisheries, with biological, social and economic input.	Interviews with stakeholders, reviews of published material, expert interpretation, economic analyses, critical element analyses	Paper 1. Fleming et al Paper 2. van Putten et al Paper 3. Norman et al Paper 4. Plaganyi et al Paper 5. Norman et al Paper 6. Norman et al
3	Develop future models of these supply chains to identify opportunities and barriers with regard to environmental change, biology, social and economic factors.	Informed by literature reviews, results from LCA, economic analyses, critical metric analysis, and perception analysis final interviews with stakeholders	Paper 1. Fleming et al Paper 2. van Putten et al Paper 7. Lim-Camacho et al
4	Develop strategies to overcome the barriers and take advantage of the opportunities. General project overview	Informed by literature reviews, results from LCA, economic analyses, critical metric analysis, and perception analysis final interviews with stakeholders	Paper 1. Fleming et al Paper 2. van Putten et al Paper 5. Norman et al Paper 6. Norman et al Paper 7. Lim-Camacho et al Paper 8. Hobday et al.

6.1 Objective 1 – Describe the current state of biology, fishery, policy and management of each case study fishery

The summaries for each fishery case study, intended to provide background information for the other project elements, were generated from reviews of existing literature and management plans and are included as **Appendix C**. In particular these summaries were used to underpin the development of the supply chains and contribute to background information for publications. Information was summarised for the following categories.

- Distribution and biology – summary of distribution and life history characters. Additional information on the biological characteristics for each species considered here is available in Pecl et al. (2011) and Welch et al. (FRDC 2010/565).
- Fishery – summary of where the species is fished or farmed, and any zoning arrangements
- Fishery management regulations, by state or zone as necessary
- Status of the fishery, as reported in recent status reports or assessments, by state or zone as necessary.
- Value of the fishery, by state or zone as necessary
- Projected changes in abundance as a result of climate change, based on published information.

6.2 Objective 2 – Develop supply chains for each of the selected fisheries

In addition to developing supply chains for each case study (**Section 6.2.1**), we also undertook a range of supporting analyses in order to support development of future adaptation options across the supply chain for each fishery. These additional analyses included social perception analysis to understand current stakeholder perceptions around climate impacts on the supply chains and inform the development of future scenarios (**Section 6.2.2**), life cycle assessment to determine areas in the supply chain that might be improved in the present day and might be vulnerable under future scenarios (**Section 6.2.3**), and several economic analyses to inform development of realistic adaptation options, and avoid mal-adaptation (**Section 6.2.4**). Finally, we develop a new approach to assessing supply chain stability, which also allowed identification of critical elements (**Section 6.2.5**).

6.2.1 SUPPLY CHAINS FOR EACH CASE STUDY

Supply chains for each fishery were developed by the project team using a range of published material, including previous supply chains (e.g. prawn aquaculture), interviews with stakeholders, and expert knowledge of each fishery system. In addition to the typical pathways, estimates of percentage flow along each pathway were included. One existing supply chain (prawn aquaculture) was used in the project. A common set of nine steps was considered for all but the prawn aquaculture supply chain (existing chain, seven steps).

1. Fishers/growers
2. Interim storage
3. Fish receivers
4. Interim transport
5. Interim storage
6. Primary wholesale
7. secondary wholesale
8. Market destination
9. Consumers

Not all sectors had elements in each of the steps, but this approach allowed generality when assessing the supply chains with LCA and stability analyses.

Draft supply chains were discussed with a subset of stakeholders for each industry, and then finalised. As differences in the supply chains (volume of product, pathway taken and destination) can arise from year to year, these should be considered as average representations over the recent past.

6.2.2 SOCIAL PERCEPTION ANALYSIS – INITIAL INTERVIEWS

Stakeholders were interviewed in the first half of the project, and in the final stages. These interviews were designed to obtain additional information on adaptation options along the supply chain for each selected fisheries, as well as determine industry perspectives on the present and future challenges and opportunities along the supply chain. At the time of the first round of interviews, only five case studies were to be included in the project, and so these also remained the focus for the final set of interviews (**Section 6.3.2**).

Qualitative, semi-structured interviews with 32 stakeholders were undertaken over a three month period in 2012 by one of the project team (Fleming). Stakeholders were chosen on the basis of their expertise in the fishery (biological, policy, management, or conservation) and/or their position along a simplified three-step supply chain (fishing – processing and distribution –marketing). Australian fisheries are managed with input from consultative groups that are representative of these different expertise (e.g. Smith & Smith 2001), and thus we expect them to have knowledge relevant to the whole supply chain. We used the simplified three-step supply chain for discussion and a slightly more detailed seven-step chain for climate-specific analyses. Contact details were sourced from industry project partners and participants approached via email or telephone with a brief description of the project and an invitation to participate.

The aim of the interviews was to gather stakeholder perceptions regarding: 1) the supply chain of their fishery; 2) potential for growth; 3) current and potential climate change impacts along the chain; and 4) potential adaptation options to climate change impacts. Interviews were largely undertaken over the phone because of the distribution of participants around Australia, although where possible interviews were undertaken face to face. Interviews lasted approximately 30 minutes and were recorded and transcribed and then sent to participants for edits if desired. Respondents were able to skip questions.

The questions were drawn from the following set, as needed during the interview, to prompt responses:

- Can you step me through your understanding of the supply chain of your industry?
- Where do you see flexibility?
- Where do you see risk?
- Where do you see potential for change and growth?
- Who would drive the change/How would it happen?
- Where do you see limitations?
- What is causing these?
- How could these be overcome?
- What changes would you like to see in the industry?
- What might drive/stop these happening?
- What support does your industry need?
- Are there any specific policy changes or information needs you would like?
- What do you think about climate change?
- Have you noticed any changes?
- What changes do you expect?
- How do you think climate change will impact your industry?
- Do you have any concerns or see any opportunities?
- What is your potential to adapt?

The goal of the data analysis was to identify climate change perspectives and adaptations as well as general emergent patterns and themes in the data. Interview transcripts were coded with the assistance of NVivo 9 qualitative data analysis software (QSR International 2009). This type of analysis is based on grounded theory approaches (Strauss & Corbin 1998; Charmaz 2006) where theory is derived in a 'bottom up' process, where codes come from the collected data. Analysis moves through processes of open/initial coding to axial coding forming categories and themes (Charmaz 2006). Due to time and capacity limitations, each industry is represented by five to seven interviews and we acknowledge there may be gaps or omissions. Nevertheless, the total number of interviews provides sufficient information to draw broad comparisons.

6.2.3 LIFE CYCLE ASSESSMENT (LCA)

Life cycle assessment (LCA) (**Box 3**) was undertaken for four sectors (**Table 1**), and the data are specific to each sector. In general, the goal of each LCA was to quantify the resource use and environmental impact along the supply chain. Full methodological descriptions for the southern and tropical rock lobster LCA are provided in van Putten et al, (Paper 2), and the same approach was used for wild prawn and the CTS.

Box 3. Life Cycle Assessment

Life cycle assessment (LCA) is an ISO standardised biophysical accounting framework used to assess and compare products and processes through their entire life cycle (from "cradle to grave") on the basis of a range of environmental impacts, including resource use, emissions, and waste products. The information produced can be used to identify key opportunities for environmental performance improvements within existing supply chains as well as the relative significance of single aspects to overall impact (*e.g.* production method, transport, processing, retail). The LCA allows for comparison between different food production systems, and offers insight towards improving the sustainability of food systems. In this project LCA was used to describe current supply chains and to examine the effect of potential adaptation options on resource use.

For example, for Tasmanian southern rock lobster, the LCA focused on resource use and environmental impact from capture and export of the SRL to the final consumer. The functional unit was 1kg of live lobster at the point of arrival in the main export market of Beijing, China. The life cycle of this product includes capture, storage, processing and transport of live exported lobsters. Consumption of lobsters in the local market of Tasmania was also modelled. The system boundary was second order in that all processes during the life cycle were included. Capital goods such as fishing boats, vehicles and buildings, were excluded as are generally of minor importance (Ellingsen & Aanondsen 2006; Ellingsen & Pedersen 2004; Hospido & Tyedmers 2005; Thrane 2004). By-catch and discards in southern rock lobster fisheries are negligible (Gardner et al. 2011) and so we considered the fishery as a single species fishery. While the processors sometimes handle other species, their volume is small and does not alter the functioning of the processing facility in terms of inputs.

Data sources – Tasmanian southern rock lobster example

Data on fuel use was sourced through catch records from the southern rock lobster (SRL) quota monitoring system, as recorded by Tasmania's Department of Primary Industries, Parks, Water and Environment. Data on fuel use was provided in dollar values and was converted to litres using historical fuel data (www.motormouth.com.au) and the current fuel discount available to fishers. Information on materials used for gear, life of gear and CPUE was provided by researchers at the Institute of Marine and Antarctic studies (IMAS), University of Tasmania, based on fishery-independent research using the same gear used in the fishery. Information on bait provision, gear life and use and anti-fouling use was obtained from informal surveys with commercial fishers. Bait was assumed to be an equal mix of Australian Salmon caught in Tasmania and Jack Mackerel and Barracouta caught in New Zealand and transported frozen by ship to Tasmania.

Questionnaires were sent to three major lobster processors for data on transport, storage, and processing. While this stage is referred to as 'processing', it consists of packaging the lobsters into boxes with wood wool and ice packs for export. The responses were averaged across the processors to create a model of processor resource use and emissions. Wholesalers were contacted for information on resource use at the wholesale stage, however this stage was assumed to include transport only as SRL is exported live and requires no cooling. It was assumed that lobsters were flown from Tasmania to Sydney and from Sydney to Beijing. Although this is the dominant supply route, several other export routes do exist (**see SRL supply chain in Section 7.2.1**).

Additional data was collected through LCA databases, including Australasian System Processes LCA, Australasian Unit Processes LCA, Ecoinvent unit processes, European Life Cycle Database, and methods library where it was not directly available from the sources outlined above.

Software and impact assessment methods specific to Australia

Impact categories were selected by their relevance to the Australian context as well as comparability with other food production LCAs. The method selected was the Australian Indicator set v2. Indicators selected from the Australian indicator set include global warming potential (GWP), eutrophication potential (EP), cumulative energy demand (CED), marine eco-toxicity and water use. Australia is an arid continent and so the inclusion of water use is an important component of life cycle impact assessment, and while it has been included in this study, this method is still provisional and requires further development (Grant & Peters 2008).

Acidification has not been included, despite its common employment in LCA studies, as the CML indicator is developed for, and based, on European conditions. While ocean acidification is of interest to seafood systems, it is caused by increased atmospheric CO_2 and thus linked to climate change so was captured under the global warming indicator (GWP). Photochemical oxidation (smog) has not been included as the level of human health damage from smog in Australia is relatively small as are the number of smog incidents in major cities (Grant & Peters 2008). Similarly, ozone layer depletion has not been included as ozone-depleting chemicals are not used in significant quantities.

6.2.4 ECONOMIC ANALYSES – MARKET INTEGRATION AND DEMAND ANALYSIS

Two economic analyses were carried out on sets of case studies. The three lobster species were grouped together, while wild and aquacultures prawns were grouped together. Market integration and demand analysis (**Table 3**) was performed separately for each species grouping. Full details of each study are provided Norman et al. in press (Paper 3) for international rock lobster, Norman et al. (Paper 5) for domestic prawn, and Norman et al. (Paper 6) for domestic and international rock lobster. With regard to international markets, the impact of the exchange rate on Australian export and domestic prices (**Box 4)** is considered where appropriate in the following analyses.

1. Rock lobster analysis – international: Price integration in the Australian rock lobster industry: implications for management and climate change adaptation

Rock lobster fisheries are Australia's most valuable wild fisheries in terms of both value of production and value of exports. Different States harvest and export different lobster species, with most of the landings being sent to the Hong Kong market. A perception in the Australian lobster industry is that the different species are independent on the export market, such that a change in landings of one species has no impact on the price of the others. We investigated the market integration of Australian exports to Hong Kong for the four species and different exporting States. We included all four species of exported rock lobster, the three focal species in this report plus the Eastern rock lobster (*Jasus verreauxi*) which is fished in New South Wales.

2. Prawn analysis: Long run price flexibilities for prawns in the Australian domestic market and the implications of climate change

The aim of this analysis is to identify whether an increase in the supply of low price farmed prawn imports from South East Asia into Australia's market impact the prices received by Australia's wild and farmed prawn producers. Climate change projections suggest South East Asia's prawn farmers could expand production and hence exports due to sea level rise increasing mangrove areas. Furthermore, the strengthening of the Australian dollar in recent years has shifted supply of high value prawns from international markets into the domestic market which is further believed to have impacted prices in the market. Increased quantities of prawns have the potential to reduce the prices received by Australian domestic producers if prawns from different locations (Australian versus imports) and production methods (farmed versus wild) are considered substitutes. We use an autoregressive distributed lag model (ARDL) to determine the co-integration between prices of Australian wild and farmed and imports in the Australian market. Then the inverse price flexibilities for both wild and farmed Australian prawns and prawn imports in the Australian market are estimated using system of equations in an error correction framework.

3. **Rock lobster analysis – domestic and international**: Price effects of climate change impacts on supplies of Australian rock lobster in domestic and international markets

This analysis considered the two main markets for Australian live and whole fresh lobster (the dominant product form): Hong Kong and the domestic market. We estimate inverse demand functions for each market, and determine the long and short run price responsiveness to changes in quantity supplied. We use these demand models in a simplified spatial equilibrium model to assess the role that market allocation may play in mitigating the impacts of exogenous changes in supply on industry revenue. The model is used to assess the optimal strategy given changes in Australian supply, exchange rates and changes in supply from competing countries (i.e. New Zealand).

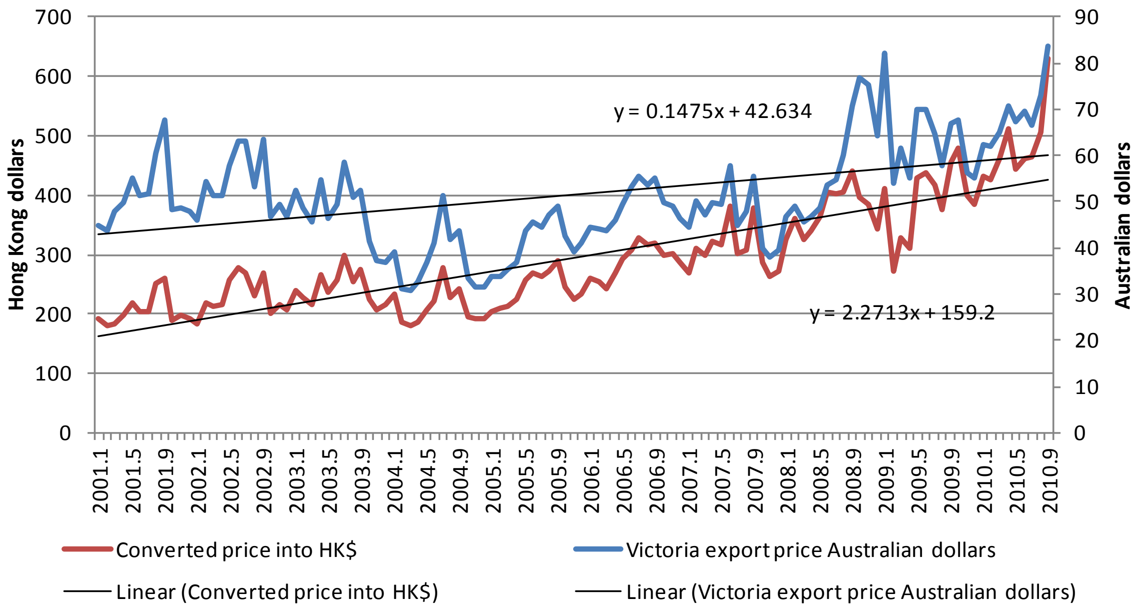
Table 3 Short explanation of the economic analysis methods used in this project.

METHOD	SUMMARY
Market Integration	Market integration analysis is a tool used to investigate the relationship between prices in the long run. Questions answered by market integration analysis include: Is there a product leading prices of other products in a market? What products compete in the same market? Market integration showing two products are part of the same market can be aggregated into a single demand equation. Market integration, however, does not preclude the possibility of price leadership. The direction of a relationship between integrated price series can be tested with the Granger causality test.
Demand Analysis	Demand analysis is the most common approach to investigate the consumers' preferences for different goods in commodity markets. Demand is influenced by several factors. The availability of prices of substitute or complement goods, population size, income, and the price of the product investigated are typically variables in a demand function. Even if markets are not integrated, supply of one species can have an impact on the price of the other. Demand analysis is useful to determine whether the market treats two species as substitute products.

Box 4. Influence of exchange rates on supply chains

An exchange rate is the price of one currency in terms of another. A stronger Australian dollar (and vice versa) will raise the cost of Australian goods in international markets and lower the cost of foreign goods in the Australian domestic market. As a result, at least in theory, the increasing price for Australian goods (because of a stronger exchange rate) in international markets will reduce demand for Australian products while Australian consumers will increase demand for foreign products in domestic markets.

For example, Hong Kong consumers pay for Australian rock lobster in Hong Kong dollars. Overall, the price they have paid since 2006 has been increasing. The increasing price in Hong Kong for rock lobster is due to the strengthening demand in this market for high value seafood products. Nevertheless, despite the increasing price in the Hong Kong market, the increase has been proportionally smaller for Australian producers due to the strengthening of the Australian dollar relative to the Hong Kong dollar. The figure shows a steeper increase in the prices paid in Hong Kong dollars by Hong Kong consumers for live Victorian Rock lobster compared to the lower increase experienced by Victorian producers exporting live rock lobster to Hong Kong. Since 2006 the prices received by Australian Victoria producers have increased by 86% (in nominal values) whereas the prices paid in Hong Kong dollars has increased by 229% for the same product.



Rock lobster price exports to Hong Kong via Victoria in Australian dollars and Hong Kong dollars

6.2.5 SUPPLY CHAIN METRICS AND STABILITY

A new analysis method based on calculation of quantitative supply chain metrics was developed as a contribution towards developing a theoretical basis for comparing and readily summarising some key features and critical elements in the supply chain (Plagányi et al. Paper 4). The method is analogous to indices used to analyse foodwebs and identify key species (Smith et al. 2011; Essington & Plagányi in prep). The network-type approach involves setting up a n x n matrix, where n is the number of elements (or nodes), and there are L non-zero elements, where L, is the number of links (or connections) in the network. Critical elements are identified as those elements with large throughput rates, as well as greater connectivity (i.e. more links in and out of an element). Larger values of the Supply Chain Index (SCI) imply greater "connectance" and importance of an element in the supply chain, and can thus be used to identify critical elements in a supply chain as well as to compare the number and structure of different supply chains. Squaring the "inflow" proportion has the effect of according more weight to high throughflows that indicate important pathways in the system. The index uses as a starting point products flowing outwards from fishers, and hence the fishers themselves will be accorded a score of zero, but will be able to identify key components of the rest of the supply chain based on the highest scores. The distribution of the SCI scores in a supply chain informs on the stability and resilience of a supply chain. In addition, the sum of the scores for each supply chain provides a single metric that captures both the efficiency of a supply chain and the connectedness. Hence a lower overall score is preferable because it is more consistent with key properties of efficient supply chains, namely greater clustering and connectivity, combined with a shorter characteristic path length (Hearnshaw & Wilson 2013). Full methodological details of this new approach are provided in Plaganyi et al. (Paper 4).

6.3 Objective 3 – Develop future models of these supply chains to identify opportunities and barriers with regard to environmental change, biology, social and economic factors and Objective 4 – Develop strategies to overcome the barriers and take advantage of the opportunities

Objectives 3 and 4 are discussed together, as the methods were intertwined. The generation of future scenarios is described in **Section 6.3.1**, the interviews with stakeholders regarding these scenarios and their adaptation responses in **Section 6.3.2**, and assessment of the impacts of these scenarios on supply chains in **Section 6.3.3.**

6.3.1 FUTURE SCENARIOS FOR THE SUPPLY CHAINS

While projections of physical change in ocean variables such as sea surface temperature as a result of climate change are generally available (e.g. from global climate models; e.g. Hobday & Lough 2011), there are generally only qualitative projections for changes in status of wild stocks for the species considered in this project (but see Pecl et al. 2009 for quantitative projections for southern rock lobster). Changes can be to the distribution of the species, overall abundance, life history processes such as growth or migration timing, and these changes may be antagonistic or synergistic. For example, recruitment of southern rock lobster has been projected to decrease in south-east Australia, while growth rates initially increase before declining as waters warm further. The time span for these future projections is also relevant, with initial increases in biomass of SRL expected to be offset by declining recruitment at some time in the future ultimately reducing stock size (Pecl et al. 2009). In other cases, projections are less time dependent - wild banana prawn stock size has been projected to increase in northern Australia over the coming century (Hobday et al. 2008) (**Table 4**). Finally, some species responses depend on the exact physical change (e.g. WRL; Caputi et al. 2010) (**Table 4**).

Table 4 Summary of projected changes for case study species (wild stocks).

SPECIES	LIKELY CHANGE INTO THE FUTURE	SOURCE
Southern rock lobster - Tasmania	Change in distribution - southward	Pecl et al. 2009
	Decline in recruitment	
	Change in growth rate	
	General decline in abundance	
	Decline in area of productive habitat on east coast	Ling et al. 2009
Tropical rock lobster	Unknown	But see - Welch et al. FRDC 2010/565
Western rock lobster	Increase or decrease in abundance depending on climate change	Caputi et al. 2010
Banana prawns	Increase in recruitment	Hobday et al. 2008
	Increase in abundance	
Commonwealth trawl sector	Species specific changes in distribution (southward movement) and abundance (declines and increases)	Fulton et al. SEAP Atlantis Project

With regard to aquaculture species, the relevant projections to the production end of the supply chain are not for stock size *per se* (this is largely controlled by the producer), but for areas of suitable growth environment (e.g. suitable water temperature for oyster cultivation). The size of the stock cultured in suitable growth environments is in turn dictated by available wild or hatchery spat (e.g. oysters), infrastructure and growing areas, market availability, and husbandry techniques (e.g. disease management). As for wild stocks, quantitative projections are not available, but some qualitative projections for future change are available (e.g. Doubleday et al. 2013).

While impacts from climate change directly affect the production end of the supply chain by changing stock sizes or areas of suitable habitat, the effect of climate change at the consumer end of the supply chain is likely to be indirect (e.g. changing consumer preferences for environmentally friendly products).

Thus, to generate a suite of future scenarios for use in this project, we developed general “scenario” categories and then outlined specific cases for each sector (*sensu* Haward et al. 2012). The set of scenarios, which we categorise here as “supply-driven” (impacts at the production end of the supply chain) and “demand driven” (impacts at the consumer end of the supply chain) changes, can be slow or fast (e.g. market closure, disease outbreaks). Thus, as reported in **Section 7.3.1,** we generated future scenarios in six general categories, three supply-driven, and three demand-driven. Each fishery was represented by at least one scenario in each category.

Supply-driven changes:

1. Slow change in abundance
2. Shock change in abundance
3. Slow change in distribution

Demand-driven changes:

4. Slow change in consumer preference
5. Slow change in market/competition
6. Shock (market closure or change)

6.3.2 SOCIAL PERCEPTION ANALYSIS – FINAL INTERVIEWS

Following from initial stakeholder interviews conducted in 2012, representatives of five fisheries sectors were re-contacted in March 2013 to identify adaptation options for fisheries supply chains given a range of future scenarios. These future scenarios, based on direct and indirect impacts of climate change, were developed by the project team, as described in **Section 6.3.1**. During the interview, stakeholders were asked to provide feedback on a future supply change scenario, and a future demand change scenario, as described in the results.

Short telephone interviews were conducted with 16 fishery stakeholders, addressing three key points: 1) what do they consider is an improved supply chain under climate change, 2) what are the impacts of the supply change on the chain, and what the ideal adaptation options are, 3) what are the impacts of the demand change on the chain, and what the ideal adaptation options are. In detail, these questions were framed as:

1. What for you is an improved supply chain from a climate adaptation perspective?
    - At the moment, how do you think are supply chains in [fisheries sector] responding to climate variability and shocks?
    - Have you seen evidence chains changing in structure as a result of these shocks?
2. Thresholds: Have you seen evidence of firms changing practices to remain viable? i.e. Changing suppliers due to low volumes or reduced quality, or even markets changing products due to price, quality or availability.
3. For each scenario/option: What do you think of this scenario?
    - How will this impact on the chain?
    - How will the chain cope?
    - What would the ideal adaptation be?
    - As a result of this change, what would an improved supply chain look like?
4. What other future options do you see?

Interview transcripts were coded with the assistance of NVivo 10 qualitative data analysis software (QSR International 2009). Adaptation options identified were then analysed against the ideal supply chain actor (fisheries, logistics and storage, marketing, governance), as well as the intended benefit of the adaptation strategy (i.e. efficiency, resilience, competitiveness). Due to the limited time available to conduct the interviews, each industry is only represented by a small number of stakeholders. As such, we acknowledge that the list of adaptation options will not be thorough, but provide a starting point for a adaptation options across supply chains.

6.3.3 LIFE CYCLE ASSESSMENT OF FUTURE SCENARIOS

The influence of the future scenarios (**Section 6.3.1**) on the supply chains required identification of potential adaptation options (**Section 6.3.2**). The influence of these options on the future supply chains has to be identified in order to identify likely changes to the LCA resource use patterns. The scenarios and adaptation options may modify the flow of product (links) through the supply chain, and thus the LCA indicators can change. For example, increasing stock abundance will lower CPUE and hence lower overall fuel use to catch the same amount of fish, reducing the LCA global warming potential (GWP) indicator under that scenario.

We explored both qualitative and quantitative changes to the LCA indicators as a result of future scenarios for those case studies with an LCA completed (SRL, TRL, wild prawns and CTS). Quantitative results for SRL and TRL are presented here (and in detail in Putten et al. Paper 2), and qualitative results presented for all four case studies in **Section 7.3.3.**

7 Results and Discussion

In the following sections, we summarize the results relevant to each Objective. Objective 1 is described in detail as an appendix, Objective 2 is present here, while Objectives 3 and 4 are discussed together, as the methods and analyses were intertwined.

7.1 Objective 1 – Describe the current state of biology, fishery, policy and management of each case study fishery

The current state of each fishery is described in **Appendix C**, and formed the information base for developing each of the supply chains and subsequent analyses.

7.2 Objective 2 – Develop supply chains for each of the selected fisheries

As reported in the following sub-sections, supply chains were developed for each fishery (**Section 7.2.1)**, stakeholders interviewed to provide insight into the issues around present supply chains (**Section 7.2.2**), life cycle assessment completed for a subset of sectors (**Section 7.2.3**), the economic analyses of the markets completed for two product groups (**Section 7.2.4**), and supply chain stability and critical elements identified (**Section 7.2.5**).

7.2.1 SUPPLY CHAINS FOR SELECTED FISHERIES

The supply chains for each industry included both the pathways that fisheries products travelled between capture and consumer, as well as the average percentage of product that travelled each pathway. Supply chains for each of the seven fisheries and aquaculture case studies are described in the following sub-sections.

1. Southern Rock Lobster supply chain – Tasmanian component

The southern rock lobster (*Jasus edwardsii*) is commercially fished from the south of Western Australia through to New Zealand. The Tasmanian component of the SRL fishery contributes 35% to the Australian total. The Tasmanian SRL fishery catch was 3083 tonnes with a value of $250m.

At the catch (or production) end of the supply chain commercial fishers in Tasmania have been loosely grouped according to their operational characteristics (**Figure 2**). Firstly, fisher quota ownership characteristics (lease quota fishing or quota owner operators) have a significant impact on their variable cost structure. Fishers are further grouped on the basis of their fishing intensity. Day fishers generally do not have the same economic and financial drivers and are often more akin to 'lifestyle' fishers.

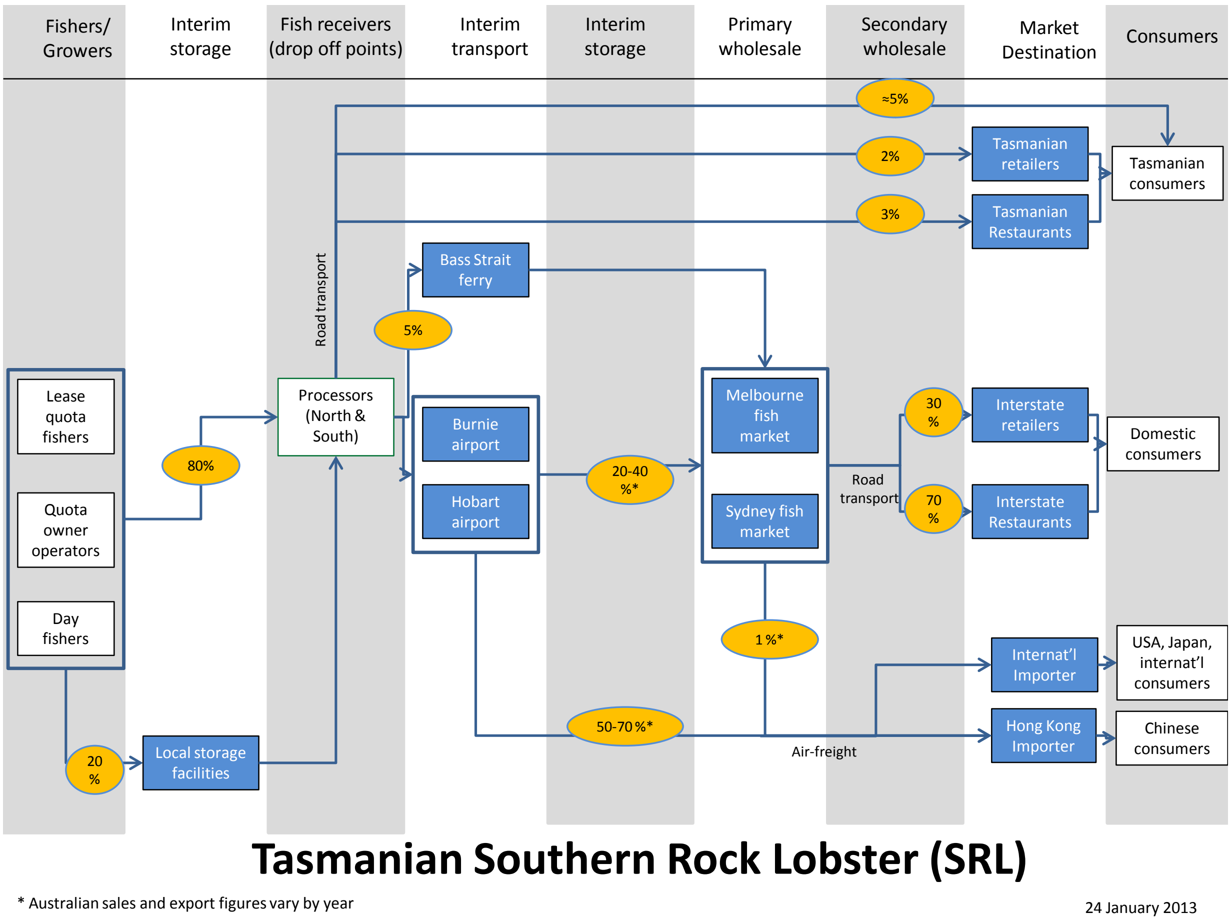


Figure 2 Tasmanian Southern Rock Lobster supply chain.

After the rock lobster is caught, approximately 80% is taken directly to Tasmanian processors. Only 20% of catch is stored in interim facilities – like holding tanks in smaller coastal towns. The catch is landed either close to the fishing grounds or in the home port. Processors or transport operators transport the catch from the place of landing to their northern or southern Tasmanian plant. The fishers make the decision on which processor to sell their catch to on several bases: the processing location is closest to the where the product is landed; the processor who pays the best price; or a lease quota arrangement between the processor and fisher.

From the processor's facilities mainly located in the north and south of Tasmania, approximately 85% of the SRL is transported by truck to Hobart and Burnie airports. From there the catch is flown, via mainland airports, to overseas export destinations (50%-70%). The Chinese export market was traditionally accessed via Hong Kong. Some of the catch (20%-40%) is retained at the Melbourne and Sydney fish markets. Approximately 10% of SRL catch is sold locally in Tasmania. There are three ways in which Tasmanian consumers access SRL product: straight from the processor (about 5%), from local retailer and supermarkets (about 2%), and in restaurants (around 3%). Domestic (Australian) consumption of SRL is mainly through restaurants (70%) and the remainder through retailers (30%).

Annual export quantities indicated in the supply chain are highly variable and depend on unpredictable external factors such as the value of the Australian dollar, global disease outbreaks like SARS, and the legality of market access. If exported quantities are low, as was the case in 2011-12, this generally means that a higher proportion of product gets sold locally in Tasmania and domestically.

2. Tropical Rock Lobster supply chain - Torres Strait sector

The tropical rock lobster (*Panulirus ornatus*) occurs in the Torres Strait, including northern Queensland and to the south of Papua New Guinea (PNG). The TRL is commercially fished in the Torres Strait and in Northern Queensland. The north Queensland fishery is managed by the Queensland State Authority while the Torres Strait fishery is managed by the Commonwealth Authority (AFMA). The supply chain discussed here applies to the Torres Strait fishery only (**Figure 3**). The estimated value of TRL fishery was $24m in 2010-11 and the catch was 704 tonnes.

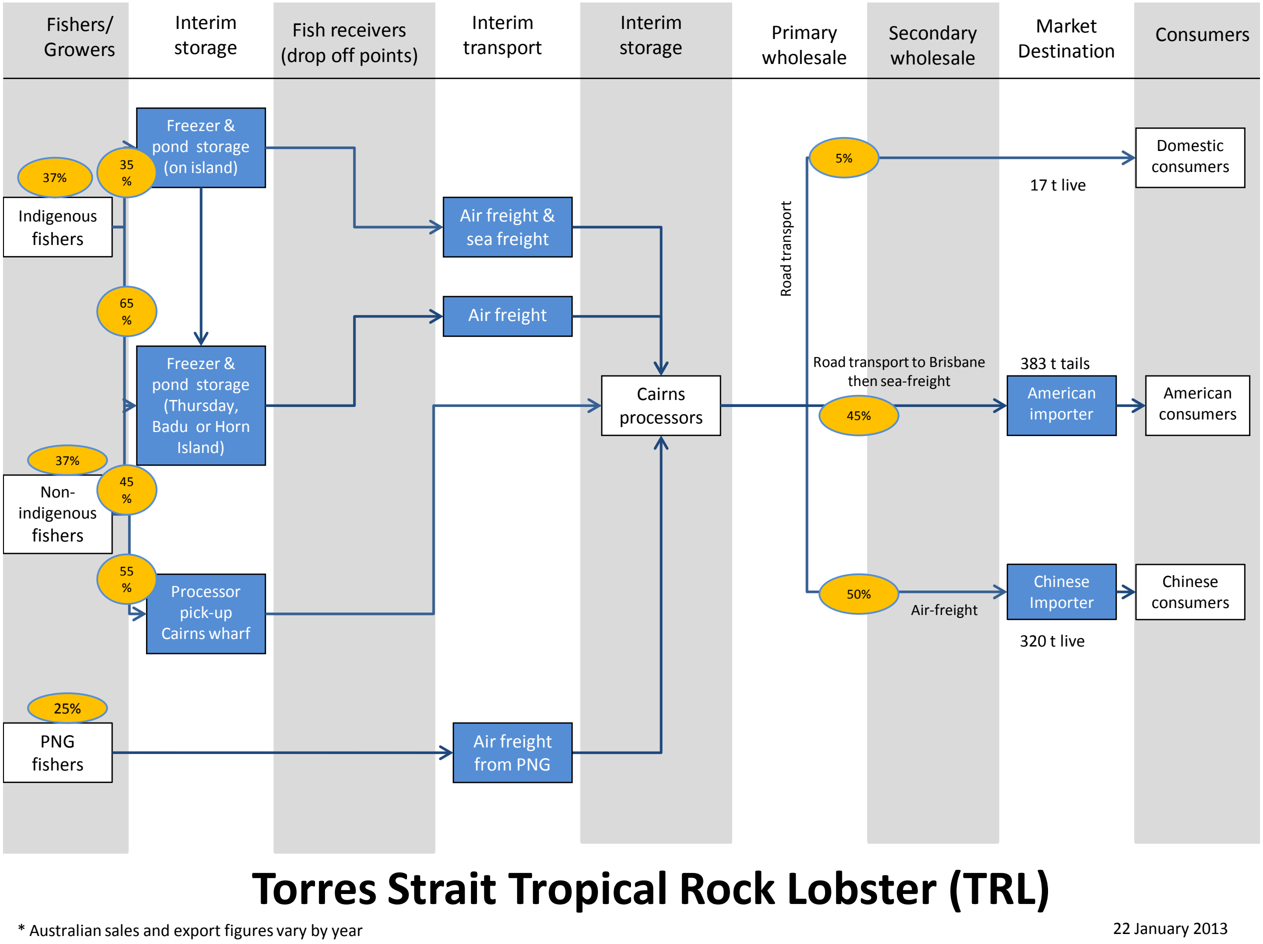


Figure 3 Torres Strait Tropical Rock Lobster supply chain.

The TRL is fished by indigenous people from Australia and PNG and non-indigenous Australians. A legislative agreement is in place that allows PNG access to 25% of the Australian catch. Non-indigenous Australians who participate in this fishery account for an annual Australian catch of 46% (around 34% taking into account the PNG catch) in 2010. The remainder is caught by indigenous Australian fishers. The three sub-fleets are shown at the production end of the supply chain. Some of the economic, social and cultural drivers to participate in the TRL fishery differ between these three fisher types. For instance, indigenous fisher participation is impacted by key economic and socio-cultural drivers, such as the availability of a government employment program, lobster prices, social capital and capacity, and infrastructure availability. The drivers to fish for TRL that apply to PNG fishers has to date not been the subject of investigation.

The TRL caught by the three fisher types shown at the production end of the supply chain, follows a different path to the Cairns processors. The product path converges at the Cairns processors. The TRL catch from the Australian Indigenous fishers is mostly transported by dinghy back to main islands like Thursday-, Badu- and Horn Island at the end of a fishing trip. Here live product is stored in tanks and tails are frozen after minor processing and packing into boxes. Product is then taken to Horn Island and air freighted to Cairns. Product landed on the smaller more remote islands (like Yam) are stored locally first then either taken to Thursday or Horn or air freighted direct from the outer islands to Cairns by charter plane. Live Australian TRL is caught mainly using hookah gear while tails are caught skindiving with a spear gun.

The non-indigenous catch is taken by divers who operate from larger vessels (mother ships) that generally carry more than one dinghy. There are some non-indigenous fishers who operate out of Thursday Island and their product follows the same path as the indigenous catch. Other non-indigenous catch is collected on the mother ship and either taken back to Cairns by vessel or taken to Horn Island and flown back to Cairns. It is unclear how and where the PNG catch is landed in that country, but the authors understand that most of it is air freighted back to Cairns before export overseas.

There are a number of Cairns processors with one sizeable operation that currently has a large market share. Due to the limited number of processors in Cairns and landing both in the Torres Strait it is somewhat unclear if prices paid by processors play a significant role in fisher choice of processor. Indigenous fisher may to some degree be bound to processors by virtue of location and loyalty.

Only a small proportion of the catch is sold directly by processors to domestic consumers. There is no information available to indicate how much of this domestic TRL is sold through restaurants and retailers. The majority of the TRL product is air freighted from Cairns and sold into the Chinese market (traditionally via Hong Kong). The Chinese market primarily imports live TRL product. The TRL tails are exported mostly by transport vessel to the USA.

As in the SLR fishery annual catches and thus export quantities vary in the TRL. Moreover the proportional export destinations as indicated in the supply chain are in reality highly variable. It is therefore important to emphasize that exports are dependent on unpredictable and uncontrollable external factors, such as the value of the Australian dollar, global disease outbreaks, competition from aquaculture product, and the legality of market access. Moreover, as there is indication that markets are integrated, stock abundance and catches in other Australian lobster fisheries will have an effect on the price of TRL product.

3. Western Rock Lobster (WRL) supply chain

The western rock lobster (*Panulirus cygnus*) occurs along the west Australian coast and is commercially fished in this State. The bulk of WRL is found between Geraldton and Perth with the Abrolhos (about 60 kilometres off the Geraldton coast) being an important source of WRL. The estimated value of WRL fishery was over $300m and the total allowable commercial catch in 2010 was 5,500 tonnes (de Lestang et al. 2012; Department of Fisheries, Western Australia 2012).

Baited pots and traps are used to fish the lobsters by approximately 280 boats (Department of Fisheries, Western Australia 2011). A quota system was implemented in the WRL in 2010/2011 season. Output management of this fishery will extend the traditional fishing season and give fishers increased flexibility to decide when to take their catch. It would seem that fishing patterns have changed markedly since the introduction of the quota system. Even though there are likely to be different fisher types with different size vessels in the WRL there was insufficient published information for sub fleets to be characterised in this current study. West Australian fishers, shown at the production end of the supply chain, are therefore grouped into one fleet (**Figure 4**).

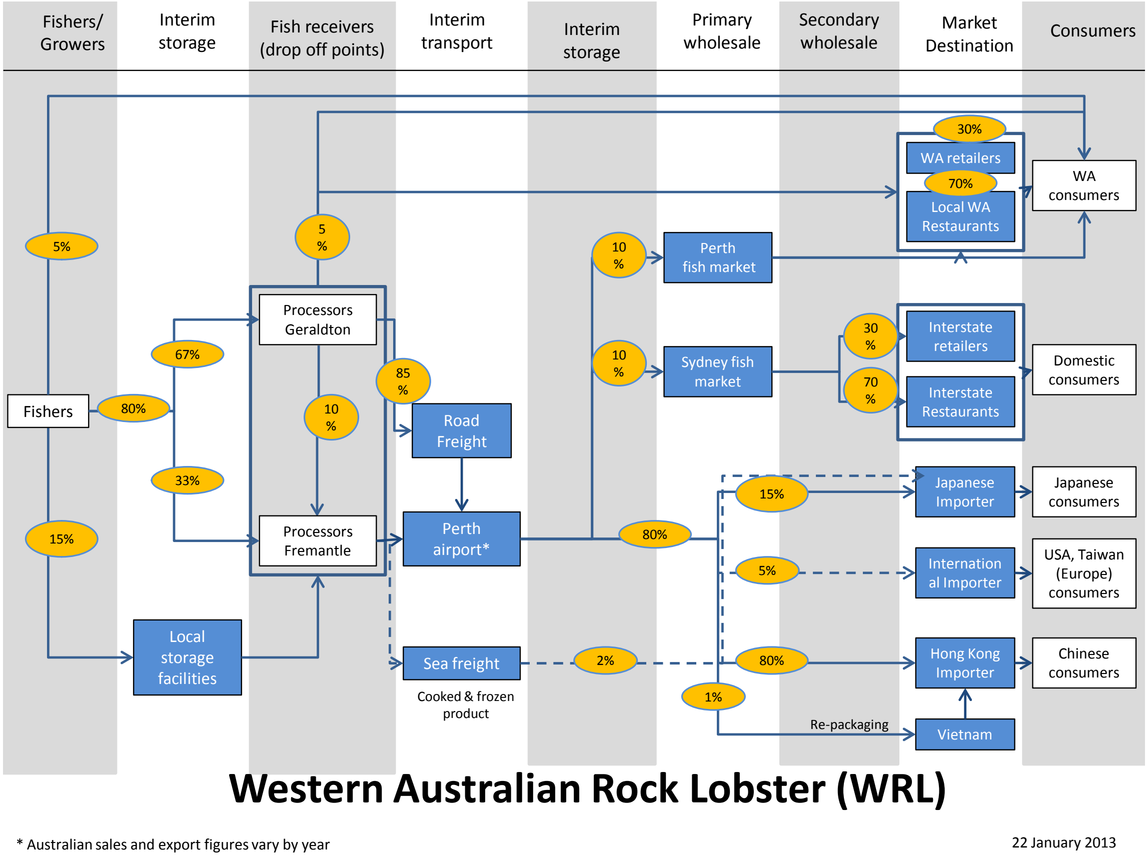


Figure 4 Western rock lobster supply chain.

Even though fishers face no local restrictions on selling their catch locally, the amount is small (estimated at less than 5% of the catch). The bulk of the catch (estimated at 80%) is landed at the main ports of Geraldton and Fremantle (but this proportion varies with market conditions). There are around 13 different processors in the WRL who will take the WRL catch. Over the past years a decrease in the number and size of surviving fishing co-operatives along the Australian coast has been observed[4]. The Geraldton fishermen's cooperative, which is 100% owned by its fishermen and license holders, continues to play a big processing role.

Some of the catch (about 15%) is landed in smaller ports like, for example Cervantes, and is subsequently taken to one of the two main processor locations. In 2005 there was some rationalization of west Australian rock lobster processors with rock lobster being throughput to Geraldton rather than some smaller processing operations, for instance in Dongara[5]. There is some transport between the two main processor locations (10%) mainly to 'fill orders'.

From the main processing facilities the product is transported to Perth airport and an estimated 10% is flow to the domestic markets in Sydney (again this amount is variable). Some product is taken to the Perth market. An average of 80% of product is air freighted overseas to three different export destinations.

Currently fewer products are cooked than in the past[6]. Cooked product was mainly for export markets other than China. Only high quality lobsters are used for whole cooked product. Cooked lobster are placed in temperature controlled cookers and then individually wrapped and packaged, and are blast frozen ready

[4] (http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/1301.0Main+Features1832012)
[5] http://www.theage.com.au/news/business/wa-lobster-players-catch-rationalisation-wave/2005/10/09/1128796410334.html
[6] http://www.brolos.com.au/images/stories/media_releases/fisheries%20bulletin.pdf

to be shipped. Japanese demand normally peaks just prior to Christmas, but preferences are strictly limited to A grade product for which premium prices are achieved. However if the catch can be taken up by one market (i.e. China) then the transport cost will be minimised by sending it all to this one only. The majority of product is now sold as live product. When export markets close or are inaccessible, lobster processors and exporters margins will be drastically reduced as they try to sell product into alternative markets. Processors and exporters often carry seasonal debt and have high overheads are generally impacted by major fluctuations in volumes.

4. Sydney rock oyster (SRO) supply chain

Sydney rock oysters (SRO) are cultivated along the coast of NSW and south-east QLD. Oystering is a fully regulated, estuary based cultivation activity. The regulation of the industry is necessary due to environmental concerns associated with intensive cultivation of seafood. Although state regulations in NSW and QLD differ, oyster growers in both states are required to obtain a permit in order to lease an area for oyster farming. About 99 per cent of the total SRO production is located in NSW; only 1 per cent of the total SRO production is located in south-east QLD (ABARES 2011).

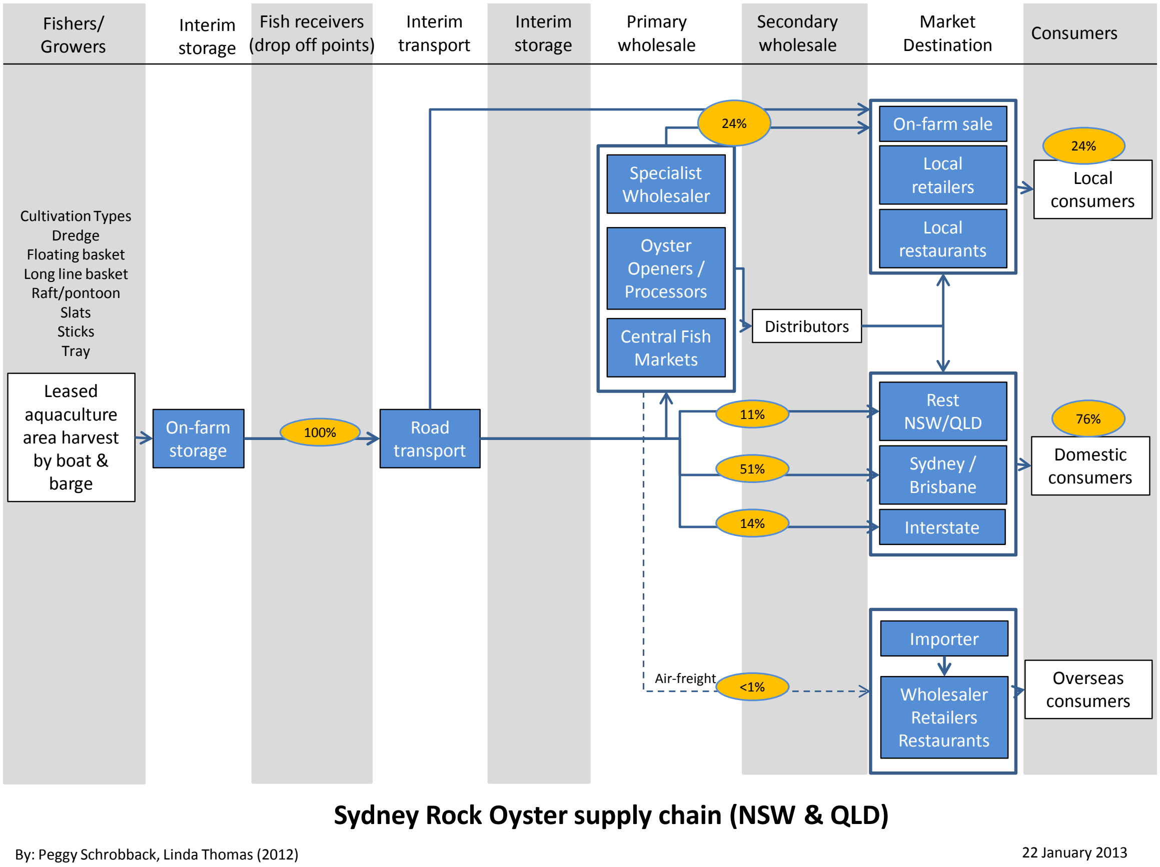


Figure 5 Sydney Rock Oyster supply chain.

The first stage of the SRO supply chain (**Figure 5**) is cultivation with the most common cultivation methods being: dredging, float baskets; long line baskets, rafts/pontoons, slats, sticks and trays (NSWDPI 2011). After harvest, the oysters are typically transported by boat or barge to the farm on land where the oysters are cleaned, graded and prepared (which may include cooling) for onward transportation to points of sale. The distribution to all of the following supply chain tiers includes a form of transportation.

The wholesale stage is comprised by oyster openers (also called shuckers) who purchase the oysters from farmers and are typically paid for opening and packaging oysters that are then distributed to other wholesalers, fish markets or distributed to different points of destinations (Cominski 2009).

The wholesale stage includes specialised oyster wholesalers who handle oysters exclusively or with only a few additional fish products, while seafood wholesalers deal a range of seafood products including oysters (Cominski 2009). Wholesale fish markets, such as the Sydney Fish Market, are not seen as a viable alternative for marketing oysters as these markets usually do not provide an oyster opening service and the volumes that are offered by these wholesalers are traditionally small and inconsistent in quality (Cominski 2009). Wholesalers who do not offer distribution or logistic services and may employ distributors for the transportation of oysters from the primary wholesale level to the points of destinations. The clear distinction between processing and wholesale level in the supply chain for SRO is not always possible since some wholesalers offer combined processing, wholesaling, and distribution services.

The market destination of the supply chain includes on-farm sales (e.g. oyster bars), fish mongers, retail stores (e.g. supermarkets) and restaurants.

There is only a very small proportion of SRO exported, predominantly to Asian markets. The exported oysters are usually directly distributed from producers to foreign wholesalers and from there distributed to restaurants (personal conversation with Ewan McAsh, November 2012).

The last tier in the supply chain of SRO is the consumer component, which includes consumers in Australia and a very small proportion of consumers overseas.

Cominski (2009) also established that foodservices, such as restaurants are the largest retail segment with about 53 per cent of sales to consumers, followed by fishmongers with 37 per cent and independent retailers and export together amounting to 10 percent of oyster sales. About 99 per cent of SROs produced are consumed by Australian customers (NSW DPI 2011). Approximately 24 per cent of oysters are sold and consumed locally, which means markets close to production area. Quantities supplied to large metropolitan markets, such as Sydney, account for approximately 51 per cent of total sales. Around 11 per cent of produced oysters are sold to other destinations within NSW, while 14 per cent are sold interstate (NWS DPI 2011).

5. Wild Banana Prawn Supply Chain –NPF sector

The Northern Prawn Fishery (NPF) is located off Australia's northern coast, and extends from the low water mark to the outer edge of the Australian fishing zone (AFZ) in the area between Cape York in Queensland and Cape Londonderry in Western Australia, occupying 771,000 square kilometres. The NPF is the Commonwealth's most valuable fishery, and Australia's largest and most valuable prawn fishery. The gross value production of the NPF is currently estimated at $88 - 90 million. The value of the fishery fluctuates widely, and is subject to a number of external factors including environmental drivers, foreign exchange rates and export market conditions.

The area is fished by 52 boats for approximately six and a half months each year. Nine commercial species of prawns are targeted, including White Banana (*Fenneropenaeus merguiensis*), Red-legged Banana (*F. indicus*), Brown Tiger (*Penaeus esculentus*), Grooved Tiger (*P. semisulcatus*), Blue Endeavour *(Metapenaeus endeavouri*), and Red Endeavour (*M. ensis*). The NPF is a demersal otter trawl fishery, employing double and quad trawls, managed through a combination of input controls (limited entry, seasonal closures, permanent area closures, gear restrictions and operational controls) which are implemented under the Northern Prawn Fishery Management Plan 1995. Production rates are heavily affected by environmental conditions and can vary considerably from year to year.

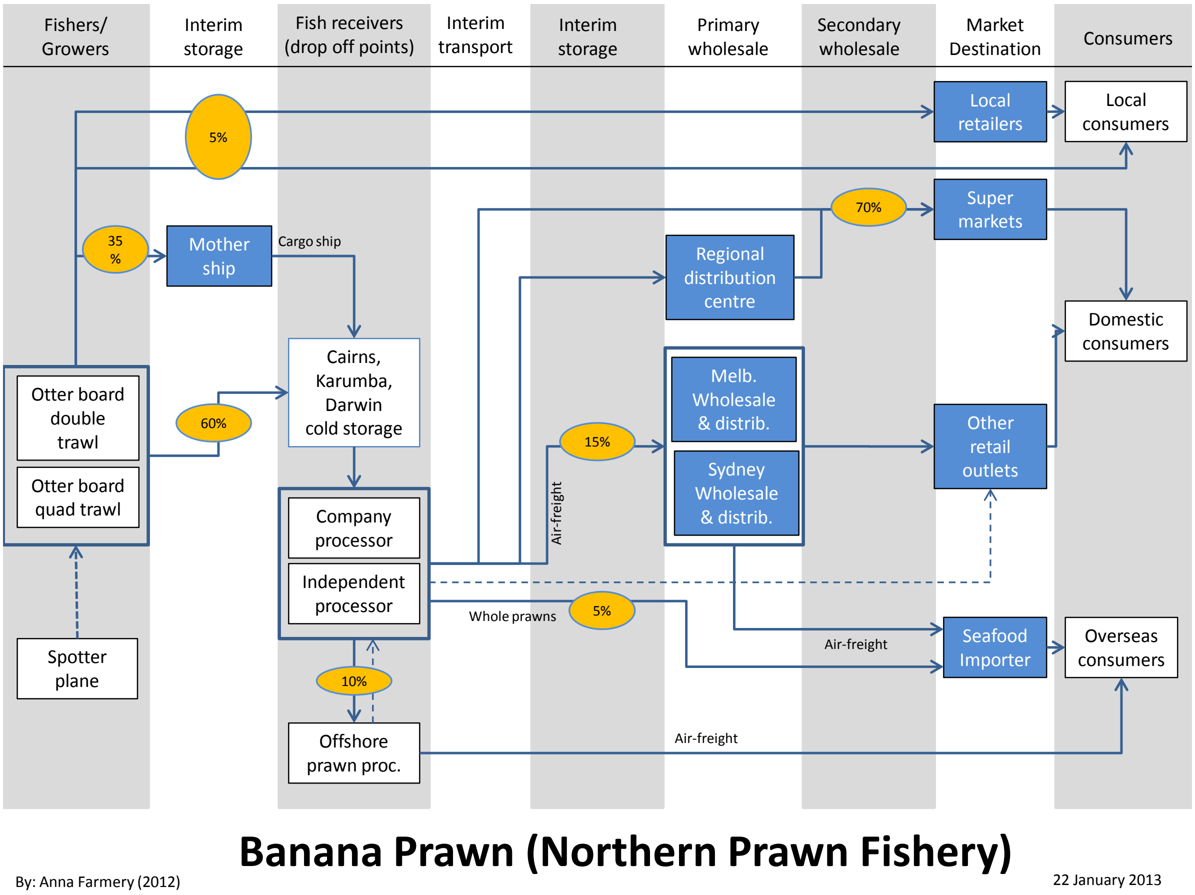


Figure 6 Northern Prawn Fishery supply chain.

Two major companies operate in the fishery, Raptis and Austral, as well as a number of independent fishers. The catch is frozen on board vessels and then unloaded either on a mothership at sea and then at storage facilities at Karumba, Darwin and Cairns, or directly at these facilities (**Figure 6**). Independent fishers typically use the mothership whereas the companies with more integrated supply chains unload direct to storage facilities. A small amount of the catch is sold directly off the back of the boat or locally in retail outlets. From the storage facilities, prawns are transport by road to processors where they are sorted and repackaged depending on quality. 70% of the catch from the processors is sent to regional distribution centres for transport to major supermarkets. A small amount is sold directly from processors (this link is not on diagram above) and 15% is sent to Melbourne and Sydney fish markets. 10%, typically lower grade prawns, is sent offshore for further processing and sent back as value added product. A fraction is sold overseas, a recent change from the vast majority of catch being exported to Japan.

6. Aquaculture Prawn Supply Chain

The greatest majority of the Australian aquaculture prawns production is sold fresh or frozen having undergone no form of value adding prior to being supplied to the consumer (CDI Pinnacle Management 2008). The supply chain shows (**Figure 7**) that their production is marketed in four ways;

(i) Via in-house or own marketing to brokers, wholesalers, direct to retailers (chain and fishmongers) and food service.
(ii) By separate seafood brokers, where Aqua Marine Marketing is an Approved Supplier to Woolworths and is their primary supplier in all of the eastern states of Australia. Blue Harvest is an Approved Supplier to Coles in NSW and Victoria.
(iii) By the Sydney Fish Markets (SFMs), either using SFMLive or the auction system.
(iv) By sales to public at the gate ("shed door"), particularly important for south-east Queensland producers.

The bulk of the production flows from the gates of the growers to the end-chain using two routes, (1) with up to two thirds via the brokers and (2) up to a third of the production from direct grower sales. Overall, the study of CDI Pinnacle Management (2008) estimates that the greatest volumes of farmed prawns in Australia are sold through the two major supermarket chains, largely in Sydney and Brisbane.

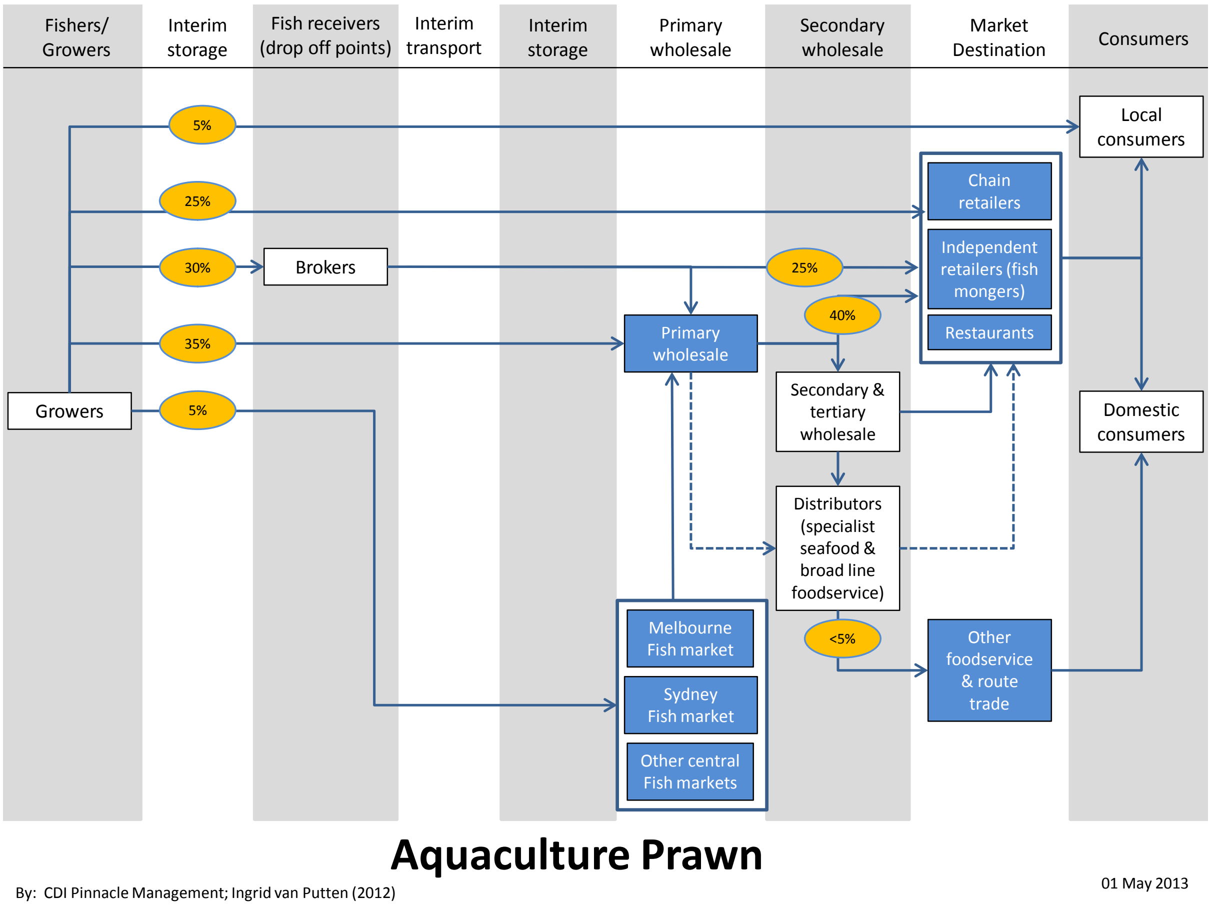


Figure 7 Aquaculture prawn supply chain (Source: CDI Pinnacle Management 2008).

This supply chain (**Figure 7**) was prepared by CDI Pinnacle Management (CDIPM) as part of a project for the Australian Seafood Cooperative Research Centre and the Australian Prawn Farmers Association (CDI Pinnacle Management 2008). The work for this supply chain was conducted between late 2007 and early 2008 in Sydney, Melbourne and Brisbane, where CDIPM met (directly and/or via a questionnaire as guide), with individuals and companies involved in Australian aquaculture prawns. These include; seafood brokers, wholesalers (agents and merchants), Sydney fish markets, chain retailers, fishmongers, and food service (restaurants, fish & chip operators). Where data was not provided (e.g. mid-chain) estimators were derived from previous studies (CDI Pinnacle Management 2008). Conversations with: Max Windfiel, Qld DAFF, and Simon Invin, CMAR, Bribie Island informed the development of this supply chain.

7. Commonwealth Trawl Sector Supply Chain

The Commonwealth Trawl Sector (CTS) is one of four sectors in the Southern and Eastern Scalefish and Shark Fishery (SESSF), and is the largest sector in catch and value terms. The fishery is located in waters between Sandy Cape in southern Queensland and Cape Jervis in South Australia. More than 100 species of finfish and invertebrates are captured in the sector, although only 20 species are targeted. The five key species that account for the majority of catch are blue grenadier, tiger flathead, orange roughy, silver warehou and ling. Of these, blue grenadier, tiger flathead and silver warehou constituted more than 54 per cent of the 2008–09 catch and Blue grenadier and flathead were the dominant species in value terms.

The fishery started in 1915 with the introduction of three steam trawlers by the New South Wales Government. The primary harvesting method now used in the sector is otter trawling; with a number of Danish seine vessels also operating. A small number of factory trawlers also operate in the fishery, primarily targeting the blue grenadier spawning fishery. Vessel numbers in the Commonwealth Trawl Sector have been in steady decline over the past decade. Management of the sector is predominantly based on output controls in the form of individual transferable quotas and total allowable catches. Under this system, there are 16 individual quota species and 29 species that are covered under basket or multispecies quotas.

The CTS, together with the Scalefish Hook Sector, are the main source of Australian fresh fish for the Sydney and Melbourne markets (**Figure 8**). Catch is landed in fish receivers in Victoria or NSW. These are cooperatives or businesses. Fifteen percent is sent directly to regional distribution centres for transportation to major supermarkets. Less than 10% is sold locally from the fish receivers and around 1% is sold from the fish receivers to export markets. The majority of the catch is sold to the Sydney and Melbourne Fish markets. The proximity of fish receiver to Sydney or Melbourne typically determines where the fish are transported to and there is some trade in product between these markets depending on demand. Fish are then auctioned at these markets and sold to restaurants, the food service market (5%) or retailers (65%). Approximately 30% of the fish sold at this point will be filleted and processed.

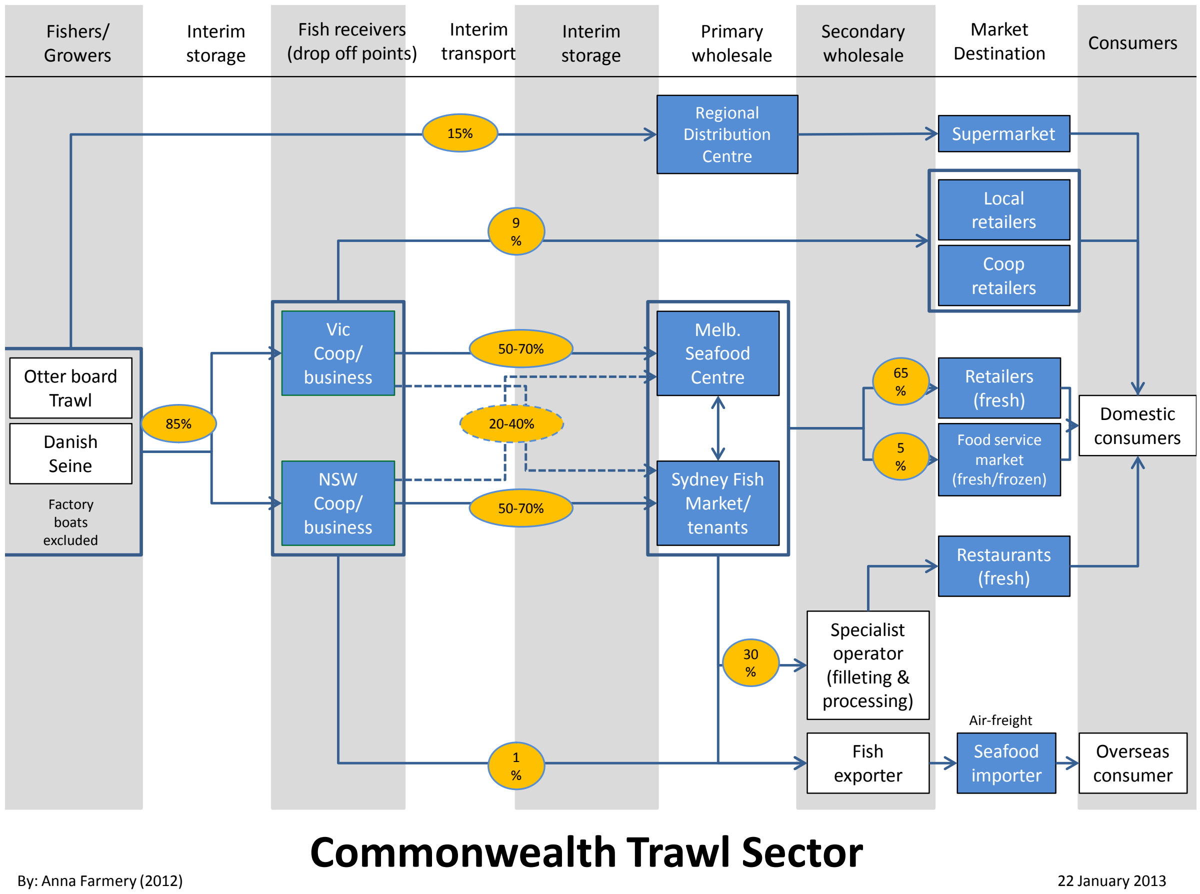


Figure 8 Commonwealth Trawl Sector supply chain.

Supply chains: Implication for adaptation

- These descriptions of the supply chains for each case study show a range of pathways that products travel from catch to consumer and some existing pathways may be more or less favoured under climate change (see subsequent sections).
- Some links or segments of the supply chain may disappear in future, and new ones may be added.
- This consistent approach to generating supply chains will allow comparisons between sectors in subsequent sections of the report.

7.2.2 SOCIAL PERCEPTION ANALYSIS – INITIAL INTERVIEWS

Qualitative, semi-structured interviews with 32 stakeholders were undertaken over a three month period in 2012 by one of the project team (A. Fleming) and covered five Australian fishery (southern rock lobster, tropical rock lobster, prawn) and aquaculture sectors (oyster, aquaculture prawn). The results from these interviews regarding the impacts of climate change on the supply chains for selected fisheries are described in detail in Fleming et al. (Paper 1). A summary of the results is provided below.

Transcripts from the 32 interviews were coded and organized into four themes and 17 categories. The four overarching themes (in order of most discussed) were: Concerns, Limitations, Opportunities and Adaptations (Fleming et al, Paper 1; Appendix 1). Across these themes, the top categories were costs, legislation and exports and industry strengths (**Figure 9**). Climate change was the equal fourth most discussed category, while limitations along the chain and management were less often discussed. Some of the categories that respondents raised were industry-specific, and illustrate key factors influencing the industry and potentially acting as barriers to prevent adaptation to climate change. Stakeholders also identified points where climate change impacts and adaptations do, or may occur.

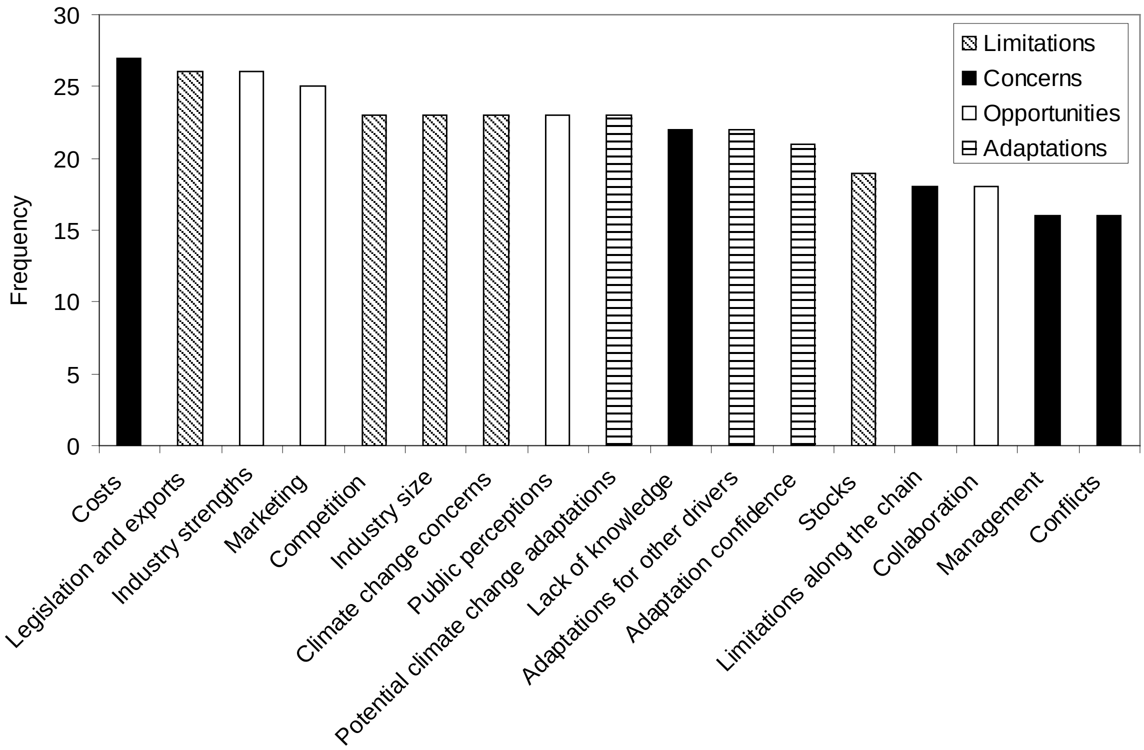


Figure 9 Frequency of category raised by interviewees (maximum = 32) coloured by organising theme.

1. Southern Rock Lobster – Tasmanian sector

Stakeholders mostly reported issues within the coding categories costs, and legislation and export. Important issues for many interviewees was a changing harvest industry structure in terms of decreasing viability and number of participants because of ageing fishers, prohibitive start up costs in terms of buying equipment and quota, as well as variability and potentially long term decreases in stocks. At higher levels in the supply chain, reliance on exports to the Chinese market, tariff compliance and impacts of currency were identified as issues.

2. Tropical Rock Lobster

Stakeholders mostly reported issues within the coding category costs and discussed the complexity of management arrangements in terms of sharing stock with Papua New Guinea and in terms of different lifestyle objectives of fishers. Potential competition from Asian aquaculture was also raised as an issue, which may be offset by ability to capitalize on reductions in southern stocks, as lobster stocks were seen to be secure. The need to increase the industry-wide production of high value live product versus low value frozen tails was another issue commonly discussed and most issues related to the harvest end of the chain.

3. Sydney rock oyster

Foremost for most industry respondents were issues in the public perception category. In addition, disease threats such as POMS (Pacific Oyster Mortality Syndrome, which does not directly affect Sydney rock oyster production) were of concern as recent outbreaks have devastated industries in Europe. As a result there was a specific focus on breeding for disease resistance. Other issues raised were the complexity of industry (remote and diverse), although this also offered potential to be flexible and regulatory limitations on land use or suitability of alternative areas. Again, most of the issues raised related to the harvest end of the chain.

4. Aquaculture prawn

Stakeholders mostly reported issues in the costs, and legislation and exports categories. In particular, concerns about regulations limiting expansion as well as marketing issues about product awareness, imports and substitution. Energy costs and infrastructure limitations were also raised as impacts mostly impacting the harvest end of the chain.

5. Wild caught banana prawn

Interviewees were predominantly concerned with issues in the competition and industry size categories. Harvesting viability, as fuel prices and marine park exclusions increased costs. The industry had recently undergone some major restructuring, downsizing the number of vessels and rearranging management. The main issues raised were related to the harvesting end of the chain.

Summary across fisheries

Overall, through the interviews we found that climate change impacts are well understood at the harvest stage, yet are not a strong driver for change higher up the chain, despite evidence for potential impacts and disruption to supply chains. Holistic adaptation planning along the supply chain, underpinned by targeted information and policy for the non-harvest elements, is needed. This effort is needed now, as some adaptation options have long lead times, and a delay in adaptation planning may limit future options (Fleming et al. (Paper 1)).

In the Australian fisheries and aquaculture sectors interviewees were focused on the capture phase with only marketing, product description and public perception being a concern for different stages along the supply chain. These perceptions do not reflect the broader importance of the post-harvest supply chain for delivery of the seafood product to consumers (e.g. transport). The pre-occupation of interviewees with the capture phase of the supply chain mirrors the focus of scientific research and literature as well as mainstream media in this area and demonstrates why a broader consideration of the supply chain is needed.

The focus on production-related impacts of climate change can be associated with observations of climate-related change identified during interviews. Most of these observations were ecological in nature, and therefore easily linked to the capture phase of fisheries. Impacts further along the supply chain can then be considered indirect, and were regarded as less certain. This uncertainty presents a dilemma for effective adaptation, as the fishery sectors considered here may fail to identify the need to plan for or, act upon, climate risks at different points along the chain, until flow-on effects become clearer.

Furthermore, while most issues related to the production stage of the supply chain, other opportunities may be unrealized. Additionally, it is important to note that participants in the industries generally felt there was a lot of potential to be constructive in terms of possible adaptation options or improvements in their industry. For example, many participants mentioned improving fuel efficiency, conducting breeding programs, altering the structure of the industry, simplifying regulations and improving public awareness as areas where gains could be made. Holistic adaptation planning along the supply chain, underpinned by targeted information for the non-harvest elements, is needed. This planning may reduce risk as adaptation options higher up the chain often have long lead times (e.g. Soosay et al. 2012), therefore a delay with regard to adaptation planning may limit future options.

Almost 30% of interviewees suggested that significant advances could be made by monitoring or modelling key impacts of climate change, indicating a requirement for further scientific information and a degree of trust in science. A number of potential policy improvements were discussed: working towards better definitions, weightings and/or prioritisation of the objectives for individual fisheries and the sector as a whole; a review of policies with the aim of moving towards a simplification and modernization of regulations to avoid current conflicts and confusions; and more support for recruitment of skilled workers, training and accreditation.

For the fishery sectors examined here, climate change is interrelated with other drivers of change (such as consumer demand) and may not be the main driver of particular change. Similar results have also been found in other primary industries, such as agriculture (Hogan et al. 2011; Park and Fleming, in review; Marshall, 2010). Another similarity is that individuals have a range of views of climate change and there remains uncertainty about impacts and adaptations, requiring monitoring, further research and evaluation (Buys et al. 2012).

Personal experiences with extreme events can have important effects on climate change perceptions (Weber, 2011), and climate change may be confused with weather (Bostrom & Lashof 2007). Therefore, timeframes for impacts and adaptations can be important. The timeframes for climate adaptation are much longer than many other chain-based strategies that can be put in place (e.g. marketing, green certifications). Thus, benefits of collaboratively adapting may not be realized for a long time. This is perhaps one reason why, in many of the industries, collaboration is not occurring effectively along the chains and as a result, adaptations may not be easily implemented. Collaboration has long been recognised as a driver for sustainable competitive advantage (Fearne et al. 2012; Soosay et al. 2012). However, collaborations are based on mutual trust and commitment. As climate change perspectives are rooted in belief systems and values (Kahan 2010) collaborative adaptation across chains is not a simple task; it requires a 'cultural fit'.

Developing a 'cultural fit' may aid collaboration as it helps establish clarity, acknowledgement and acceptance of different values from people at different points in the chain who are working towards some shared values and a shared sense of purpose (Nir 2011). Developing a shared understanding and sense of purpose relies on commitment from industry stakeholders to participate and work together in good faith and for mutual benefit, across different elements of the supply chain.

There are also a number of external drivers that need to be managed alongside adaptation options. In Australia, seafood supply chains are influenced by a reliance on imported product to supply domestic requirements and a focus on export for the most valuable products (Spencer & Kneebone 2012). Therefore the value of the Australian dollar, import/export regulations, trade relations and transport options are all factors impacting decisions and flexibility to change. Increasing demand alongside the inability to increase take from wild stocks for some species means that in the longer term there may be an increased reliance on farmed fish. However, market price preferences, a lack of infrastructure and restrictive regulation in some regions means that this sector is often less cost competitive than imports (Spencer & Kneebone 2012).

Overall, taking a supply chain perspective for the fisheries examined here showed that industry participants are aware of opportunities and barriers across most of the chain, especially at the production end of the chain. Whilst the production end of the chain received most attention, adaptation planning is unlikely to be successful unless all links in the supply chain are considered. In all industries there is a broad range of participant perspectives on how climate change will impact fisheries and a need for more understanding of particular impacts, while at the same time a need to build in flexibility and resilience across the chain. A clear need is to improve collaboration along the chains in each industry through more communication and transparent interactions as well as improved marketing – as they are critical to supporting future adaptation and ongoing supply of seafood.

INITIAL INTERVIEWS: Implication for adaptation

- Policy can guide climate adaptation at many points along a supply chain.
- In the marine sector, climate impacts and possible adaptation options along seafood supply chains are not well documented, and therefore policy makers are not well informed regarding policy barriers and opportunities.
- From the perspective of resource users, several key policy areas need to be addressed to improve business performance and support climate change adaptation. These include adjusting current policies at the harvest stage of the supply chain and supporting holistic planning at subsequent stages of the supply chain.
- Specific examples of policy-related barriers include restricted access to international markets due to trade agreements (rock lobsters into China), closed seasons for harvest that coincide with high price periods for product (rock lobster), and water quality regulations that limit industry expansions (aquaculture prawn).

7.2.3 LIFE CYCLE ASSESSMENT

1. Southern Rock Lobster LCA – Tasmanian component

The environmental impacts of the southern rock lobster are dominated by both the capture and export stages. The export stage consisted of truck transport and international airfreight and resulted in a higher contribution to Global Warming Potential (GWP) and Cumulative Energy Demand (CED) than the capture stage, which included fuel use on the fishing boat, gear and bait (**Table 5**). The capture stage showed clear dominance for Eutrophication Potential (EP), due to the diesel fuel use on the fishing boats as diesel engines are a major source of emissions of nitrogen oxides (NOx). The capture stage also dominated Eco-toxicity, due to the use of anti-foul on the boats. The main ingredients included copper (oxide and thiocyanate), resins, and zinc oxide. Some paints included biocides such as Diuron.

Processing is minimal for live lobsters and contributed little to the environmental impacts except for water use. Water use is highest in the capture phase; however a distinction here is that the water use in the capture phase was for the production of diesel as opposed to actual water use in the processing stage. Transport by road also contributed little to the overall environmental footprint. The LCA results in the form of impact categories are presented in **Figure 10**. As each category is measured in a different unit, the results are presented as percentage contribution.

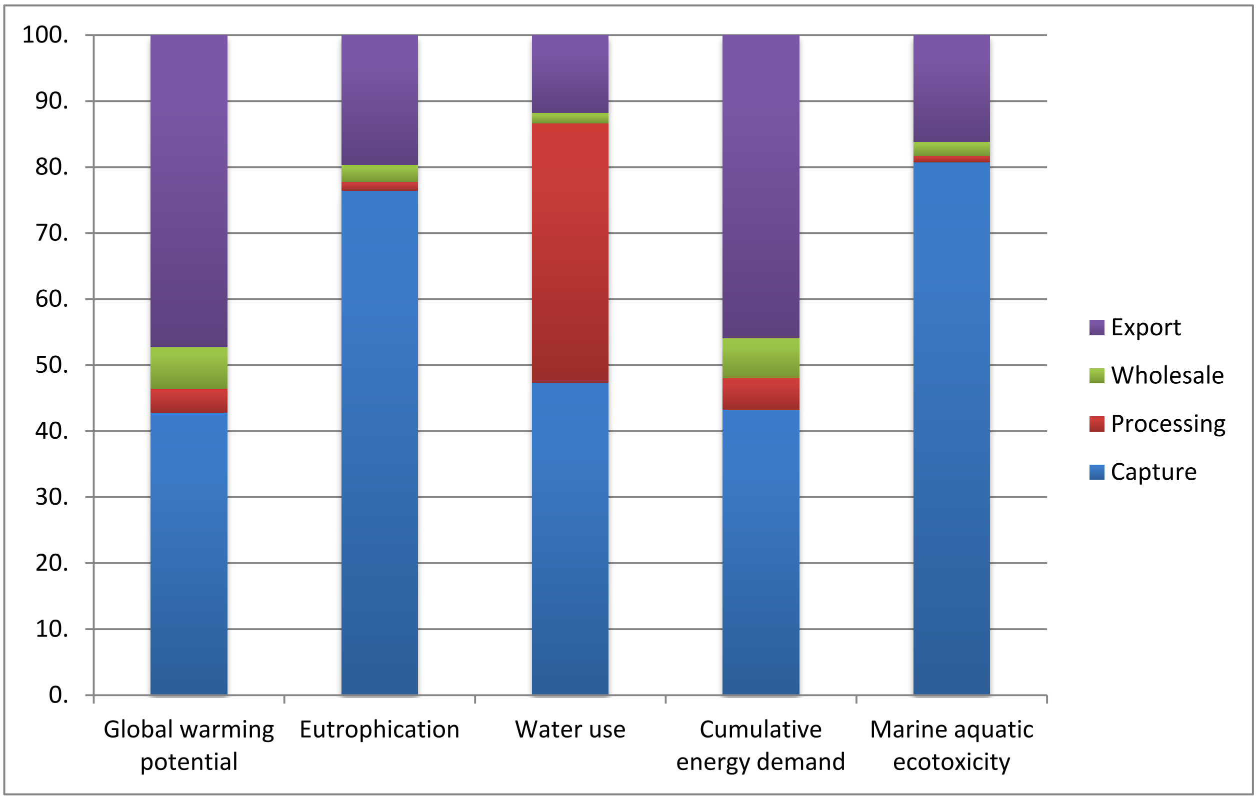


Figure 10 Contribution by category to the life cycle impacts of SRL exported live.

Bait was responsible for 9% of the total global warming emissions (GWP) and 11% of the cumulative energy demand (CED) (**Table 5**). Bait also dominated the water use indicator at the capture stage because of the use of cardboard packaging during transport of bait. Gear contributed little to any of the indicators at the capture stage, except for water used in the production of steel for the pots.

Table 5 Life cycle impacts of processes at each stage of the SRL supply chain. GWP: Global warming potential, EP: eutrophication potential; CED: cumulative energy demand; Water: freshwater use; Ecotox: ecotoxicology

LCA STAGE	PROCESS	GWP (KG CO_2E)	EP (KG PO_4E)	CED (MJ)	WATER (M^3)	ECOTOX (DAY)
Capture	Fishing boat engine	10.77	0.02	157.32	0.00	4.72E-11
	Bait	2.97	0.01	51.51	0.01	1.69E-11
	pot	0.07	0.00	1.28	0.00	6.66E-11
	antifoul	0.01	0.00	0.17	0.00	2.50E-10
Processing	Electricity	0.28	0.00	7.53	0.00	9.52E-13
	Water	0.00	0.00	0.02	0.01	5.81E-15
	Packaging	0.05	0.00	3.53	0.00	0.00E+00
	Road transport	0.83	0.00	12.07	0.00	3.65E-12
Wholesale	Road transport	0.00	0.00	0.06	0.00	1.68E-14
	Domestic airfreight	2.03	0.00	29.67	0.00	1.01E-11
Export	International airfreight	15.23	0.01	222.99	0.00	7.61E-11
	Road transport	0.01	0.00	0.17	0.00	5.03E-14
Total		32.26	0.04	486.32	0.02	4.72E-10

2. Wild Banana Prawn LCA – NPF sector

The capture stage of the banana prawn supply chain is the largest contributor to three of the five indicators measured (**Figure 11**). The capture stage accounts for 80% of the Global Warming Potential (GWP), over 90% of Eutrophication and 80% of the cumulative energy demand (CED). Fuel use was the main contributor to these impacts (**Table 6**). Processing accounted for almost 90% of the water used and 75% of the marine aquatic toxicity.

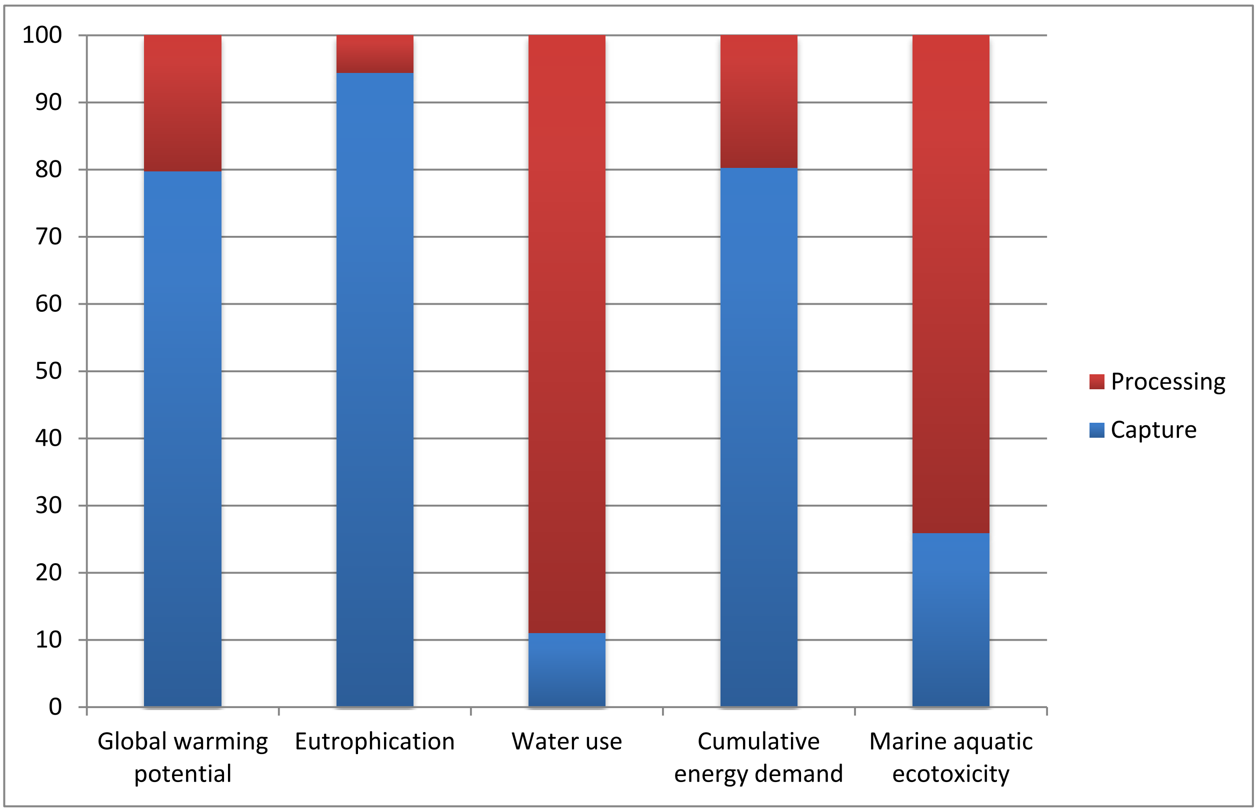


Figure 11 Contribution by category to the life cycle impacts of 1kg of frozen Banana prawns at wholesale.

Table 6 Life cycle impacts of processes of 1kg of frozen banana prawn at each stage across the supply chain. GWP: Global warming potential, EP: eutrophication potential; CED: cumulative energy demand; Water: freshwater use; Ecotox: ecotoxicology

LCA STAGE	PROCESS	GWP (KG CO_2E)	EP (KG PO_4E)	CED (MJ)	WATER (M^3)	ECOTOX (DAY)
Capture	Fuel	5.528935	0.013057	80.79594	0.000613	2.42E-11
	Spotter plane	0.026069	1.42E-05	0.39301	2.98E-06	1.19E-13
	Antifoul	0.001489	2.16E-05	0.030196	7.58E-05	4.51E-11
	Packaging	0.052855	5.03E-05	0.920878	0.001609	3.18E-12
	Gear	0.029133	1.74E-05	0.648762	5.33E-05	9.31E-13
Subtotal		**5.63848**	**0.013161**	**82.78879**	**0.002353**	**7.35E-11**
Processing	Water	0.012161	4.33E-06	0.136168	0.015908	9.68E-13
	Transport	0.223999	0.000104	3.246381	2.46E-05	9.82E-13
	Electricity	1.194472	0.000671	16.97838	0.002967	2.08E-10
Subtotal		**1.430632**	**0.000779**	**20.36093**	**0.018899**	**2.1E-10**
Total		7.069112	0.01394	103.1497	0.021253	2.83E-10

3. Commonwealth Trawl Sector LCA

Two fisher types (Danish Seine and trawl) are considered in this LCA. The capture stage of fresh fish supply chain is the main contributor across all indicators assessed (**Figure 12**). It is responsible for over 90% of the global warming potential (GWP), almost 100% of Eutrophication, over 70% of water use, over 90% of cumulative energy demand (CED) and 85% of marine ecotoxicity. Fuel use on the boats is the main contributor to impacts and trawl boats are typically less efficient than Danish seiners (**Table 7**). Resource use at wholesale and processing is minimal given that the fresh is supplied fresh not frozen and no value adding other than gutting and filleting takes place.

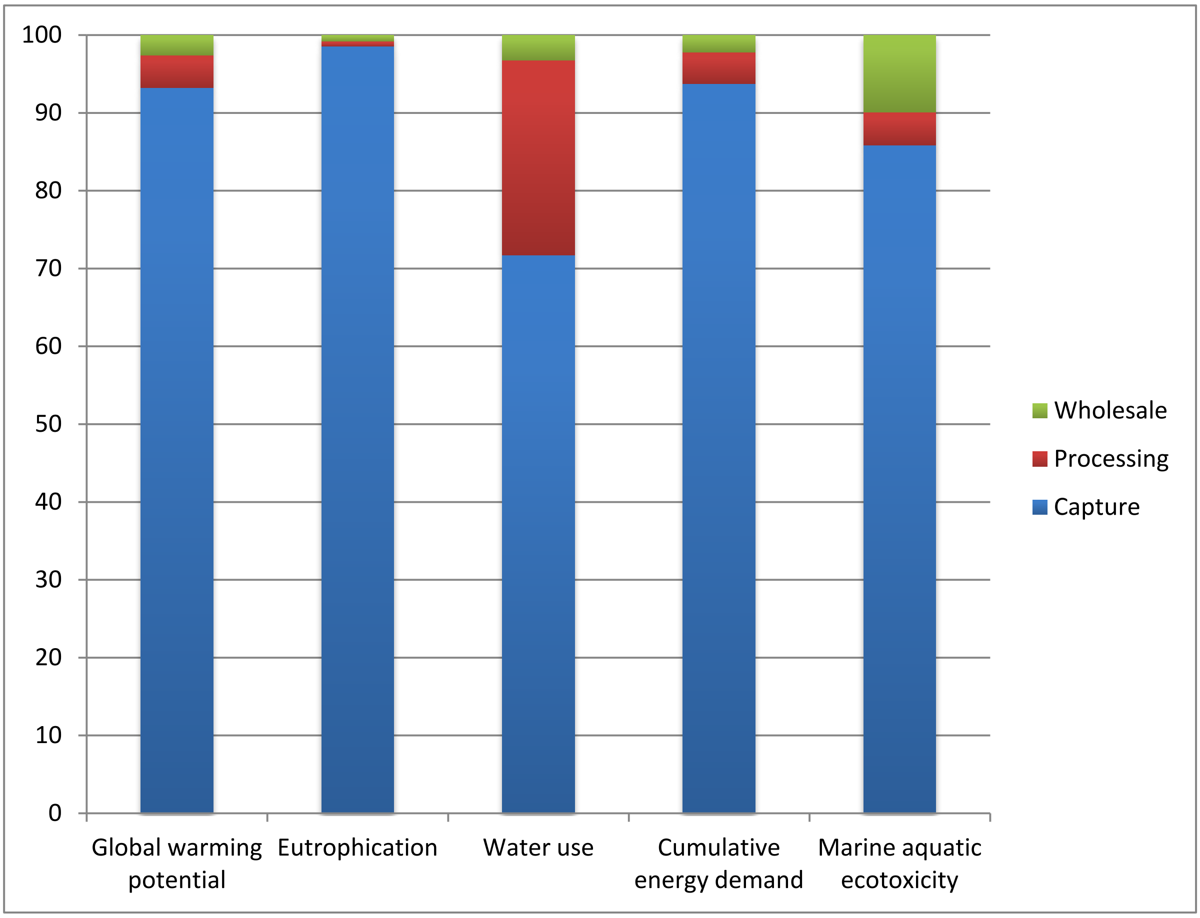


Figure 12 Contribution by category to the life cycle impacts of 1kg whole fresh fish from the CTS at wholesale.

Table 7 Life cycle impacts of processes at each stage per kilo of fish from the Commonwealth Trawl Sector supply chain. GWP: Global warming potential, EP: eutrophication potential; CED: cumulative energy demand; Water: freshwater use; Ecotox: ecotoxicology

LCA STAGE	PROCESS	GWP ($KG\ CO_2E$)	EP ($KG\ PO_4E$)	CED (MJ)	WATER (M^3)	ECOTOX (DAY)
Capture	Trawl	2.963356	0.006521	47.30776	0.002846	3.17E-11
	Danish seine	0.191956	0.000429	3.225649	9.17E-05	2.59E-12
Subtotal		**3.155311**	**0.006951**	**50.53341**	**0.002938**	**3.43E-11**
Wholesale	Water	7.42E-05	2.58E-08	0.000831	6.87E-05	5.97E-15
	Transport	5.80E-02	4.82E-05	0.837849	6.35E-06	2.51E-13
	Cleaning chemicals	9.19E-05	1.54E-07	0.001348	1.13E-05	7.33E-13
	Crates	0.001366	2.78E-07	0.03525	5.05E-06	5.23E-15
	Electricity	0.028658	9.71E-06	0.313639	4.23E-05	2.96E-12
Subtotal		**0.088241**	**5.83E-05**	**1.188918**	**0.000134**	**3.96E-12**
Processing	Water	0.000105	3.99E-08	0.001199	0.000773	7.92E-15
	Packaging	0.016097	1.19E-05	0.760009	5.72E-05	1.08E-12
	Transport	0.011859	9.41E-06	0.172147	1.31E-06	5.18E-14
	Electricity	0.11255	2.36E-05	1.236705	0.000194	5.44E-13
Subtotal		**0.140611**	**4.5E-05**	**2.17006**	**0.001026**	**1.69E-12**
Total		**3.384163**	**0.007054**	**53.89239**	**0.004098**	**3.99E-11**

4. Tropical Rock Lobster LCA - Torres Strait sector

In the TRL, a total of five fisher typologies were distinguished in the LCA. These represent the commercial indigenous and non-indigenous groups represented in the supply chain (**Figure 3**), who sell product as tails or live lobster, and non-commercial indigenous fishers (**Table 8**). On a per kilogram basis, the two indigenous segments have the highest GWP for the capture phase, while with regard to export, the live product has the highest GWP, and overall total.

Table 8: Global warming (kg CO_2 per kg lobster) for TRL fisher types. TRL is divided into 5 categories based on fisher typology and market destination.

FISHERY	FISHER TYPES	PRODUCT TYPE	CAPTURE -AT BOAT	PROCESSOR - PACKAGING & FACTORY	EXPORT - AT MARKET	TOTAL
TRL	Non-indigenous (commercial)	Tails	1.75	0.02	1.58	3.35
TRL	Non-indigenous (commercial)	Live	1.75	1.41	10.60	13.76
TRL	Indigenous (commercial)	Tails	3.19	0.02	1.58	4.79
TRL	Indigenous (commercial)	Live	3.19	1.41	10.60	15.20
TRL	Casual indigenous	Tails	1.90	0.02	1.58	3.50

However, when the LCA for these groups is scaled to the total catch, the global warming potential (GWP) across these five fisher types presents a different picture **(Figure 13**). The commercial non-indigenous live fishery type has the greatest overall GWP of the five types. Similar patterns of environmental resource use result for the other environmental indicators (data not shown), due to the greater catch of this segment of the fishery.

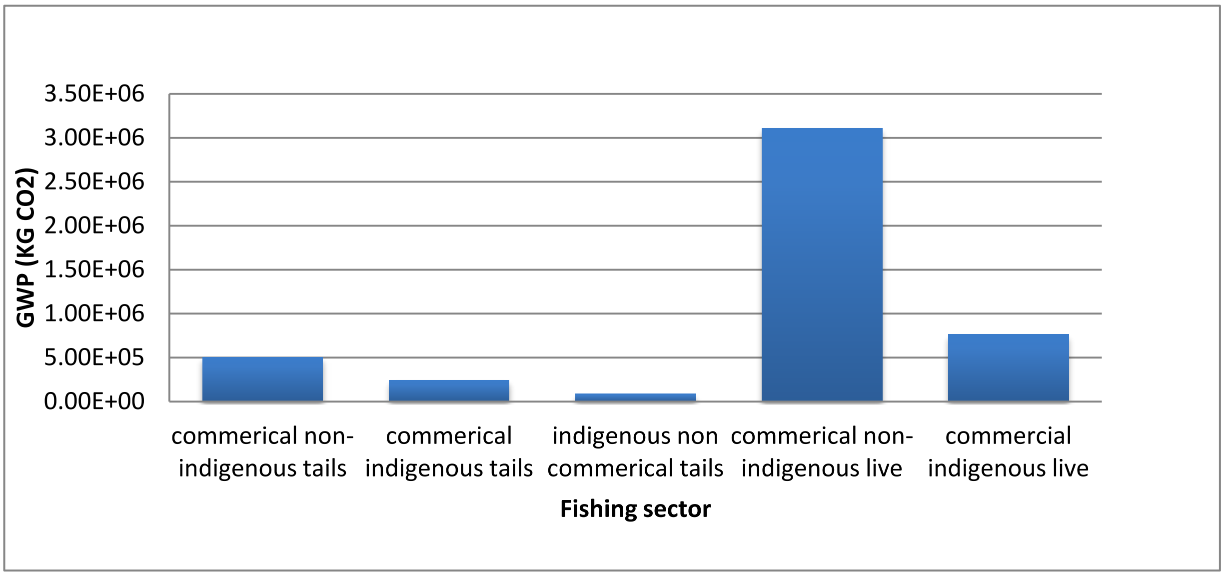


Figure 13 Global warming potential (GWP) for five fisher-types in the tropical rock lobster fishery for their entire catch (status quo).

5. Quantitative comparison across lobster fisheries

The environmental footprint of fisheries across their supply chains can also be determined with LCA. For example, the contribution to global warming for the SRL is estimated at 32.24 kg CO_2 per kilo of lobster product (**Table 9**). For the TRL alone, the non-indigenous sector for tails contributes least to global warming (3.35 CO_2 per kilo of lobster) while the indigenous commercial sector for live product has the highest global warming contribution of 15.20 kg CO_2 per kilo of lobster. The SRL contribution to global warming is approximately 4.5 times as great as the TRL based on the estimated sectoral average for the TRL of 11.03 CO_2 per kilo of lobster product[7] (**Table 9).**

The SRL fishery, which produced 63% of the combined 1,926 t of SRL and TRL product, contributes 83% to the combined global warming of 47 t CO_2 for the fishery (2011). This difference is mainly due to the significantly lower contribution of the dive based capture phase of the TRL fishery. The per kilo of product contribution to global warming in the TRL capture is mostly from the two stroke engines used by the local indigenous fishers on their dinghies, which is still considerable lower than the use of large vessels using pots in the SRL capture phase. At the export end of the supply chain the SRL also makes a greater contribution to global warming per kilo of product due to the greater freighting distance from the southern end of Australia compared to the far north (TRL). The analysis shows that the capture methods in lobster fisheries can have a marked impact on their environmental footprint.

Additional comparisons of environmental indicators across these two loster fisheries, such as eutrophication potential (EP) and cumulative energy demand (CED) are presented in van Putten et al. (Paper 2).

Table 9: Global warming (kg CO_2 per kg lobster) for SRL and TRL fishers. TRL is divided into 5 categories based on fisher typology and market destination.

FISHERY	FISHER TYPES	PRODUCT TYPE	CAPTURE - AT BOAT	PROCESSOR - PACKAGING & FACTORY	EXPORT - AT MARKET	TOTAL
SRL	All commercial fishers	Live	13.80	1.16	17.28	32.24
TRL	Non-indigenous (commercial)	Tails	1.75	0.02	1.58	3.35
TRL	Non-indigenous (commercial)	Live	1.75	1.41	10.60	13.76
TRL	Indigenous (commercial)	Tails	3.19	0.02	1.58	4.79
TRL	Indigenous (commercial)	Live	3.19	1.41	10.60	15.20
TRL	Casual indigenous	Tails	1.90	0.02	1.58	3.50

[7] TRL fishery average is based on the average contribution of the five fishery components to total catch (based on the past 5 years).

LCA Analysis: Implication for adaptation

- SRL: The environmental impacts of the southern rock lobster are dominated by both the capture and export stages. The export stage consisted of truck transport and international airfreight and resulted in a higher contribution to Global Warming Potential (GWP) and Cumulative Energy Demand (CED) than the capture stage, which included fuel use on the fishing boat, gear and bait. Reducing these inputs could improve the environmental impact.
- Wild prawns: The capture stage of the banana prawn supply chain is the largest contributor to three of the five indicators, suggesting a focal area for improvement in future.
- CTS: The capture stage of fresh fish supply chain is the main contributor across all indicators assessed. Thus a focus on reducing the environmental impacts should also focus at this part of the supply chain.
- TRL – Different fishing methods vary dramatically in their use of environmental resources.
- The contribution to GWP can vary widely between similar species, and the location in the supply chain with highest GWP may be targeted for improvements.

7.2.4 ECONOMIC ANALYSES – MARKET INTEGRATION AND DEMAND ANALYSIS

A total of three economic analyses were completed, and full results of each study are provided in Norman et al. (paper 3) for international rock lobster, Norman et al. (paper 5) for domestic prawn, and Norman et al. (Paper 6) for domestic and international rock lobster. These results helped to suggest future scenarios and guide development of appropriate adaptation options.

1. Rock lobster analysis – international: Price integration in the Australian rock lobster industry: implications for management and climate change adaptation (Norman et al. 2013, Paper 3)

Our results indicate all four species and producers/export states are perceived to be substitutes for one another, so that, in the long run, prices paid to operators in the industry will move together. The integrated nature of the Hong Kong export market for Australian lobster suggests that the potential impacts of alternative fisheries management and development strategies at State and species levels cannot be considered in isolation, at least from an economic perspective. In addition, impacts of external shocks affecting production in one state (e.g. climate change) can be expected to affect all Australian lobster fisheries.

2. **Prawn analysis:** Long run price flexibilities for prawns in the Australian domestic market and the implications for industry growth (Norman et al. in press, Paper 5)

Prawn prices received by Australian producers are at historic lows coinciding with increases in volume of lower value prawn imports. Development of appropriate management strategies requires understanding the interaction between imports of prawns and Australian production of wild and farmed prawns. We use an autoregressive distributed lag model (ARDL) to determine the cointegration relationship between prices of Australian wild-caught prawns, Australian farmed prawns, and prawn imports in the Australian market. The inverse price flexibilities for Australian prawns and prawn imports in the Australian market are then estimated using systems of equations in an error correction framework. The results suggest an asymmetrical relationship: that increased imports depress the prices received by Australian producers, but not vice versa. Continuing increases in global prawn aquaculture production are likely to result in further declines in prices of both domestically produced and imported prawns on the Australian market in the future.

3. **Rock lobster analysis – domestic and international**: Price effects on supplies of Australian rock lobster in domestic and international markets (Norman et al. Paper 6)

The export of high-value seafood to international markets is a volatile business strategy. A case-in-point is the international trade in wild-caught rock lobster. We illustrate the effect that changes in demand, the exchange rate and consumer expenditure have on Australian lobster prices and hence industry revenue. An understanding of these forces can improve the business strategy for producers (fishers) and lead to a more profitable fishery. We develop inverse demand models of the two largest markets for Australian lobster: namely the market for live lobster in Hong Kong (China) and the Australian domestic market.

Our derived price flexibilities highlight that consumer expenditure in Hong Kong has the largest effects on Australian prices followed by changes in Australian supply, the exchange rate and changes in exports from New Zealand. In the domestic market, prices were significantly impacted by changes to Australian domestic supply but consumer expenditure had no effect. Johansen cointegration analysis confirmed spatial integration between the markets indicating producers adjust supply between the Hong Kong and domestic markets. Thus, price effects are not only dependent on demand in each market but also on the interaction between the markets. We combined our derived price flexibilities for each market in a simple spatial equilibrium model (SEM) to simulate the adjustment of supply between the two markets and how it affects prices. Our simulation results highlight the adaptive capacity of the industry to deal with shocks when it is able to allocate supply between the Hong Kong and domestic markets.

The model only considers two markets, as this represents the majority of sales. Inclusion of more markets in the supply chain would increase the resilience of the industry to shocks, as the effects can be dissipated through relatively smaller changes in each market. The ability to reallocate product between different markets provides some adaptive capacity in the industry to respond to exogenous shocks. Preliminary results suggest that the optimal allocation is largely driven by the relative price flexibilities, with greater proportional changes observed in the markets that had the lowest price flexibility (i.e. the most elastic).

In all cases examined, changes were observed in both markets rather than just changes in one. This largely reflects the spatial equilibrium condition – if the price differential between markets exceeded the transport cost, then a profit maximising producer would allocate more product to the higher priced markets until prices declined to the new spatial equilibrium. This is analogous in traditional microeconomic theory to the profit maximising condition that marginal benefit (i.e. of trade) equals the marginal cost (i.e. the transport cost).

The US market for tails is also an alternative market. This is a “residual” market to a large extent, as not all lobsters survive harvest and storage. The tails of those that die are sold on a separate market and are essentially a separate product (and to some extent are unintentional by-products of the live-based fishery). The model was run allowing an option of selling to the US market at a substantially lower price, but in all cases in the above simulations (and even additional simulations removing the Hong Kong market) the price for tails was not sufficient to actively attract additional product. Hence, while an important market for the by-product, it is not likely to be a major influence on the ability of the industry to respond to exogenous shocks.

Economic analyses: Implications for adaptation

The economic analyses suggest that some adaptation responses, such as reducing the supply at the production end in an attempt to boost prices will not be successful. These analyses indicate constraints on the range of adaptation options.

1. Rock lobster – international markets: The integrated nature of the Hong Kong export market for all the Australian lobster species suggests that the potential impacts of alternative fisheries management and development strategies at State and species levels cannot be considered in isolation, at least from an economic perspective.
2. Domestic prawns: An increase in imports will depress the price received for Australian domestic prawns, however, a decrease in imports is not likely to lead to an increase in price for local prawns. Thus, attention to increasing the consumer preference for Australian prawns may lead to increases in proportion of the domestic market share.
3. Rock lobster – domestic-international interactions: the markets are already linked, and product flow is such that the proportion to each market is already responsive to overall price. Market coordination is thus important for Australian producers.

7.2.5 SUPPLY CHAIN STABILITY

The individual Supply Chain Index (SCI) scores for each element in the individual supply chains were ranked to identify critical elements within that supply chain (and can be compared within and between supply chains) (for full details see Plagányi et al. Paper 4). Although simple, a pie graph shows the distribution of these scores at a glance, with the most critical elements represented by the larger pie slices, colour coded for all elements with a score that is 1% or more of the total summed score. From highest to lowest scores, the colour coding used is roughly red (>20%)-orange-green-blue-purple. Additional highlights to the red and orange boxes emphasize where the critical elements are and how they are distributed.

1. Southern Rock Lobster (SRL) supply chain – Tasmanian sector – critical elements

The key elements identified by application of the SCI to the SRL supply chain are respectively, Hobart airport, the processors and Chinese consumers (**Figure 14**). Under scenarios of changing climate, it is important for a supply chain to be agile (Christopher and Towill 2001) so that the chain and its processes are able to respond flexibly to change. Ensuring the resilience of key elements in a chain may thus be particularly important in maintaining the longer term stability of a supply chain. Hence for SRL, the airport has limited flexibility to shift and adapt and emphasis should be placed on supporting and building the resilience of other key elements such as the processors and Chinese consumers. For example, focusing effort on firmly establishing Chinese trade agreements may provide the most critical scope for growth and building stability in the SRL supply chain. At the other end of the supply chain, the processors are highlighted as important elements and hence the resilience of the chain can be strengthened by focusing interventions on building the stability of this component. For example, given the threats and challenges of algal blooms (associated with warming water and enhanced transport), contingency plans need to be in place and options explored to improve the ability to predict the extent and timing of blooms.

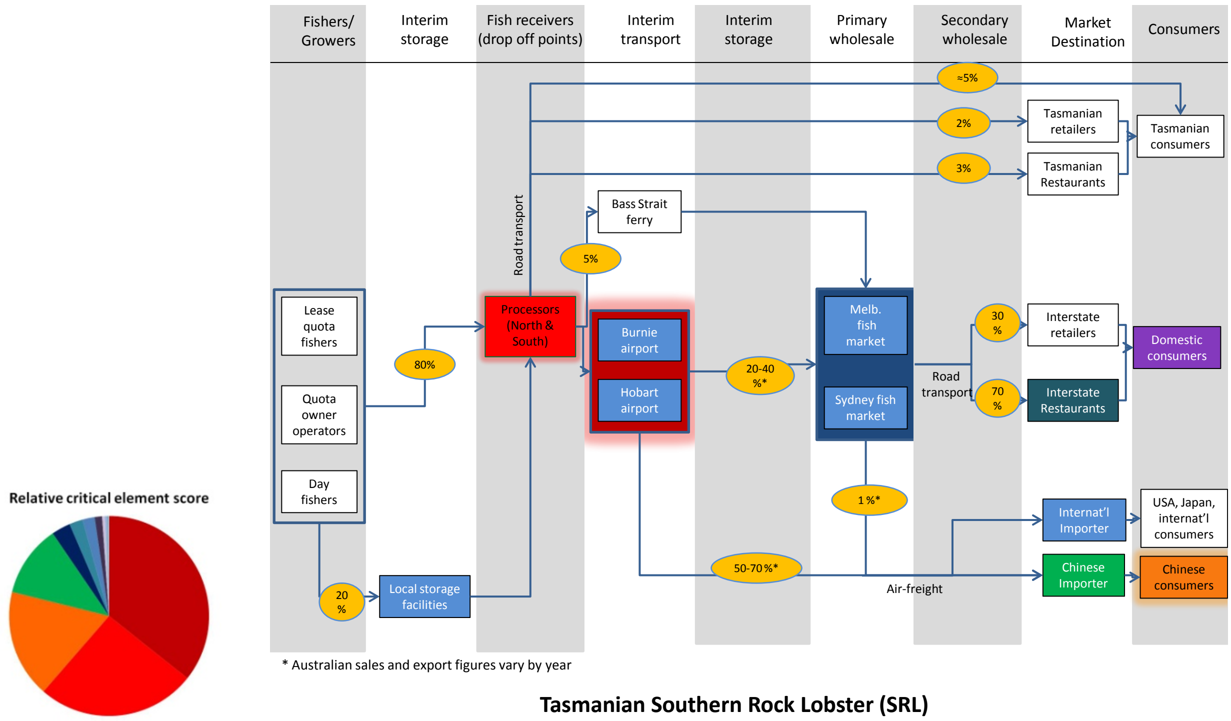


Figure 14 SRL supply chain with colour coding to highlight key elements, with the relative distribution of these scores summarised in the accompanying pie diagram.

The overall supply metric for SRL is 2.02 which can be compared with other supply chains, as well as with alternative sensitivity scenarios for the SRL chain itself (**Table 5**). In general a lower score represents a more stable and diffuse supply chain. This is because of the reliance of the index on the square of the term describing the amount of product flowing through an element. If a large volume of product flows through a single element compared with a scenario in which half this amount flows through each of two elements, then it can be shown mathematically that the former score for two elements will be twice that of the latter, i.e. higher scores suggest greater dependence on fewer elements and hence a potentially less flexible supply chain that cannot respond and adapt as readily.

Sensitivity scenarios

A number of sensitivity scenarios were considered as follows:

A) Base Case
B) Sensitivity 1 - Airport: reduce the dependence on Hobart airport by assuming that half the product is transported instead via the Bass Strait ferry;
C) Sensitivity 2 - Chinese Consumers: reduce the amount of product flowing to the international Chinese market, and redirect it to the local Australian mainland consumers instead;
D) Sensitivity 3 - Domestic Consumers: as in C), but further remove Tasmanian consumers link such that almost all product flows to Australian mainland consumers.

Under Sensitivity (B), the supply metric decreases from 2.02 to 1.65, indicating an improvement in the stability/robustness of the chain as the critical dependence on the airport is relieved to some extent through the (theoretical) introduction of an additional important transport element. The individual key score of the airport is reduced so that under this sensitivity the processors and Chinese consumers become the new key elements (**Figure 15**). This scenario demonstrates the improvement in resilience which can result from lessening the dependence on a single key element and strengthening or adding alternative complementary pathways and connections.

Sensitivities (C) and (D) explore the effect of narrowing the current distribution of product from several consumers to progressively fewer, first by substantially decreasing the flow to international markets and secondly by completely removing the Tasmanian consumer pathway. As expected, the overall supply metric worsens from the base-case value of 2.02 to 2.29 under (C) and to 2.75 under (D). The Chinese consumers lose their ranking as one of the key elements and the Melbourne fish market becomes relatively more important instead (**Figure 15**).

In the first instance, this scenario highlights the general principle that reducing connectivity and linkages in a supply chain decreases its stability and agility. In this example the removal of elements, and hence reduction in total path distance, does not compensate in the SCI score for the negative effect of reducing connectivity (because the SCI score accords higher weight to connectivity). The fact that the entire supply chain did not collapse when first one and then two pathways were reduced and removed, nonetheless suggests that the SRL supply chain has a reasonably robust resilience, in the sense of being able "to resist change and preserve connectivity after nodal removal" (Albert et al. 2000). In these illustrative sensitivity scenarios, it was assumed that Australian mainland consumers would be able to absorb additional product, but in reality the resilience of this supply chain depends in part on the extent to which this assumption holds.

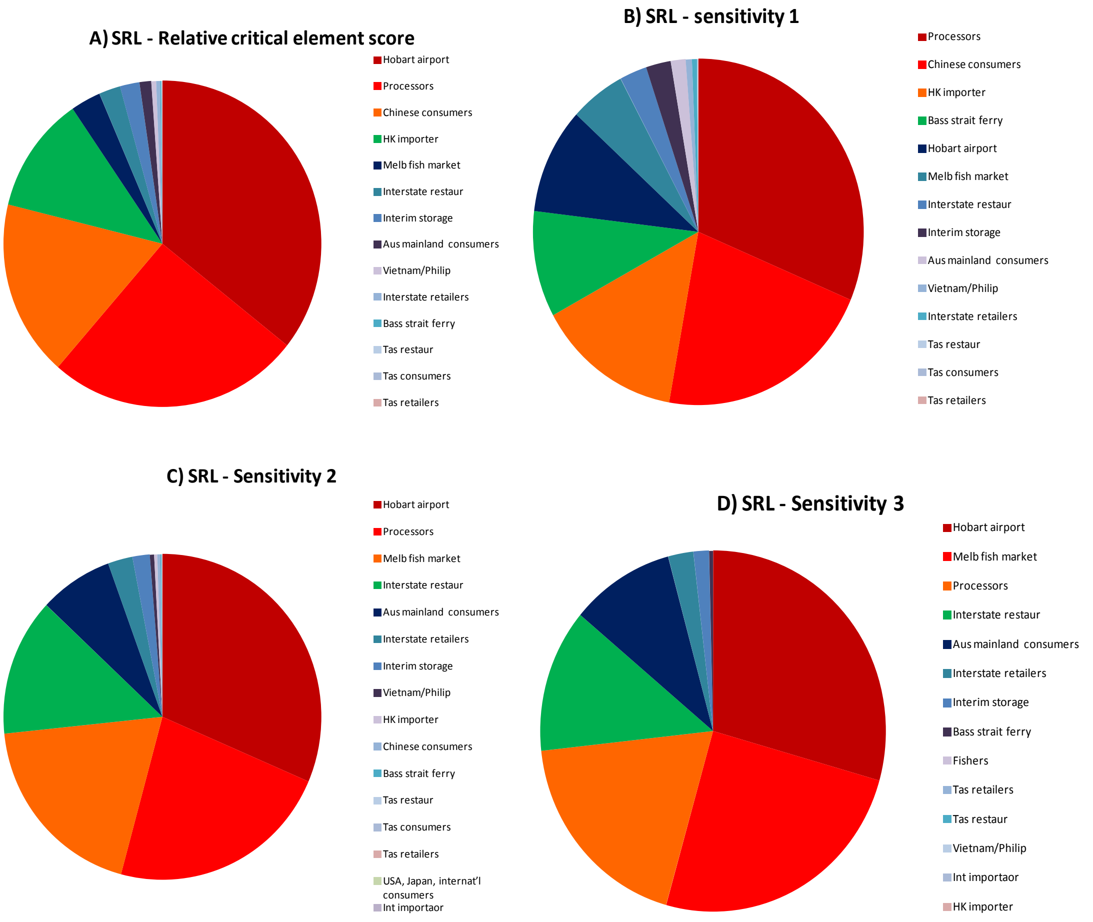


Figure 15 Comparison of sensitivity scenarios (see text for detailed descriptions) using the SRL supply chain as an example.

2. Tropical rock lobster (TRL) supply chain – critical elements

For TRL, the SCI identified the Chinese and U.S. markets as key elements (**Figure 16**), suggesting that the key mechanism for stabilising this supply chain is to reduce uncertainty in supplying these markets. However the individual element scores were not as high as was the case for the key SRL elements, with a more even spread of important elements, suggesting less critical dependence on key elements, and hence greater agility. This is even more the case if one considers that there is an additional connection or supplier of product (not considered in this study given logistical constraints), namely the Queensland East Coast lobster fishery which targets the same species, albeit in a different geographical area, and also supplies the Cairns processor. The TRL supply chain appears to be strongly demand-led. Maintaining and strengthening relationships with international markets is thus key to underpinning the success of this supply chain.

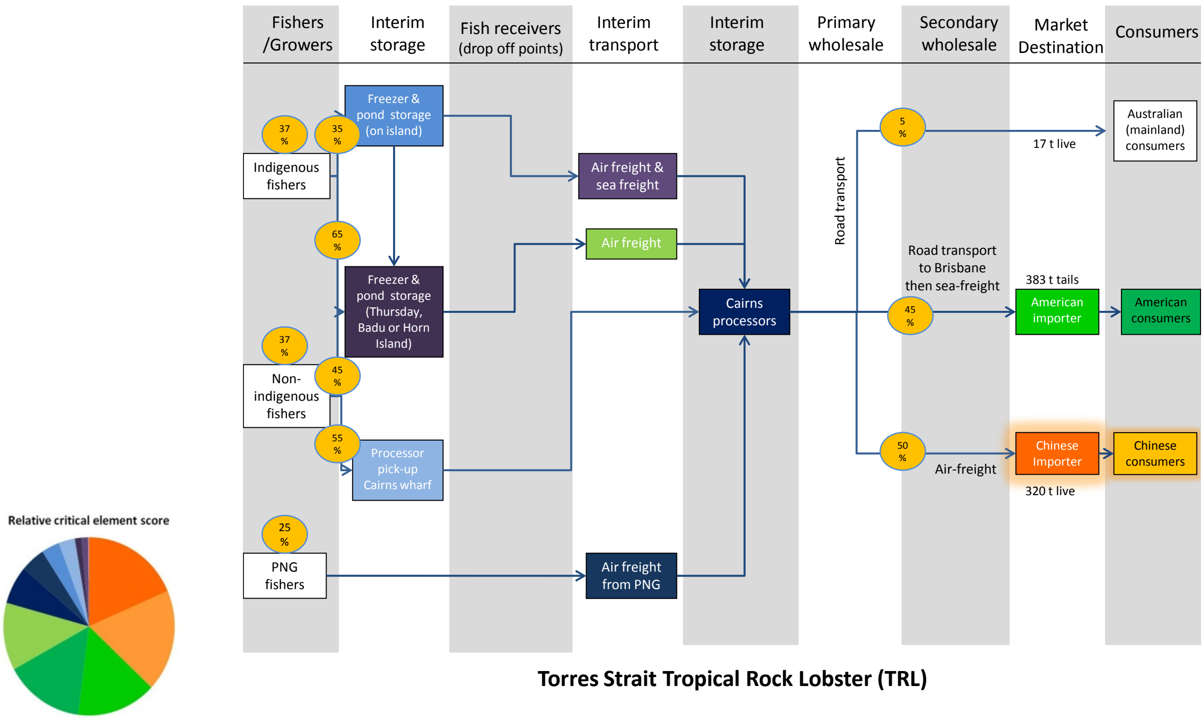


Figure 16 TRL supply chain with colour coding to highlight key elements, with the relative distribution of these scores summarised in the accompanying pie diagram.

3. Western rock lobster (WRL) supply chain – critical elements

The WRL supply chain had a comparatively high number of elements and links (**Table 5**). The SCI identified the Chinese consumers and associated Hong Kong importer as key elements, followed by the Geraldton processors (**Figure 17**). The distribution of the individual element scores was more similar to SRL than TRL.

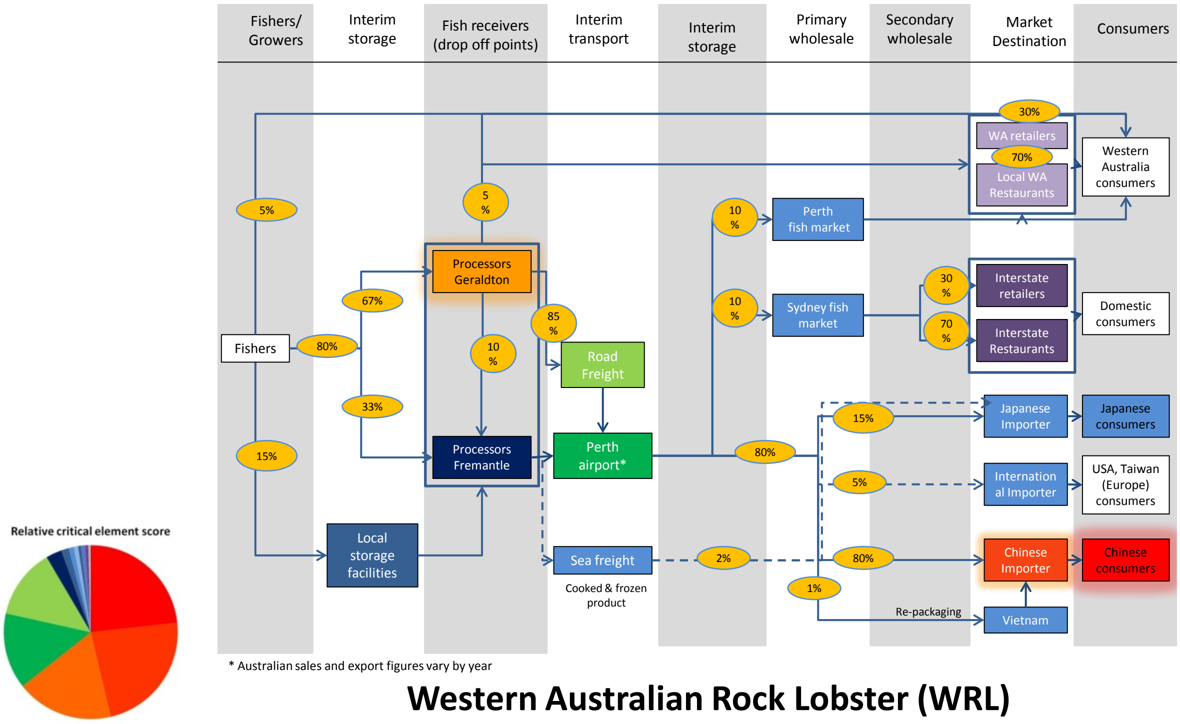
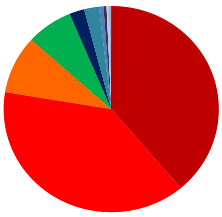


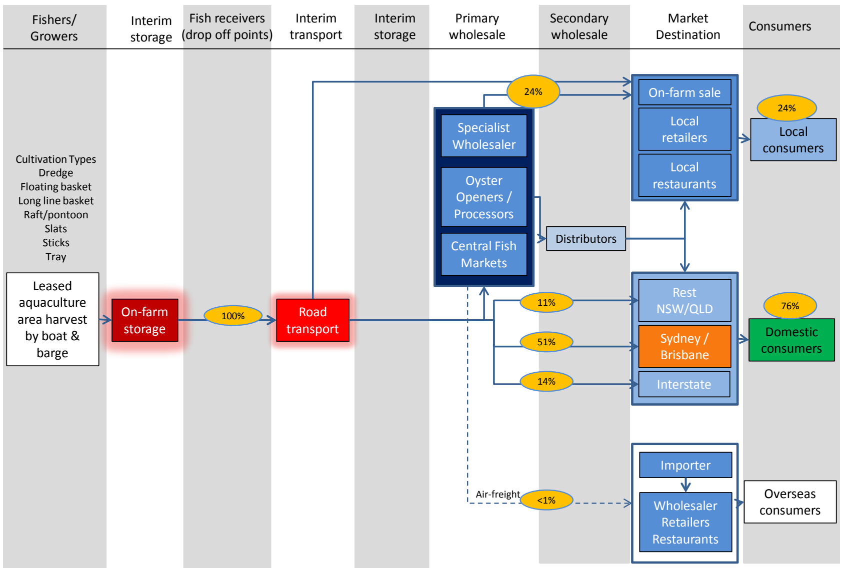
Figure 17 WRL supply chain with colour coding to highlight key elements, with the relative distribution of these summarised in the accompanying pie diagram.

4. Sydney Rock Oyster Supply Chain – critical elements

The Sydney rock oyster supply chain is highly linear at the supply end, with the interim storage and transport identified as key elements (**Figure 18**). The dominance of these two elements suggest that this supply chain may be particularly vulnerable to external factors impacting on these key elements, and hence that this chain may not be as resilient as some of the other examples. Storey et al. (2006) suggest that ideally managed supply chains are demand-led. The Sydney rock oyster example shows low-resilience in contrast to the SRL example above because removal of either of the two key elements would result in a collapse of the entire supply chain and failure to preserve connectivity.

Relative critical element score





Sydney Rock Oyster supply chain (NSW & QLD)

Figure 18 Sydney oyster supply chain with colour coding to highlight key elements, with the relative distribution of these scores summarised in the accompanying pie diagram.

5. Wild Banana Prawn Supply Chain - NPF sector – critical elements

For Northern Prawn Fishery banana prawns, the supermarkets and the domestic consumers they supply were identified as key elements (**Figure 19**). This highlights that it is important to secure a good working arrangement with the supermarkets. For example, the stability of the supply chain can be improved by focusing effort on determining what factors (e.g. steady supply, minimum volumes of product) are necessary to maintain this as a successful link. In general the banana prawn supply chain showed a relatively good spread of key elements across the chain, and hence an ability to change and adapt connections in response to exogenous shocks.

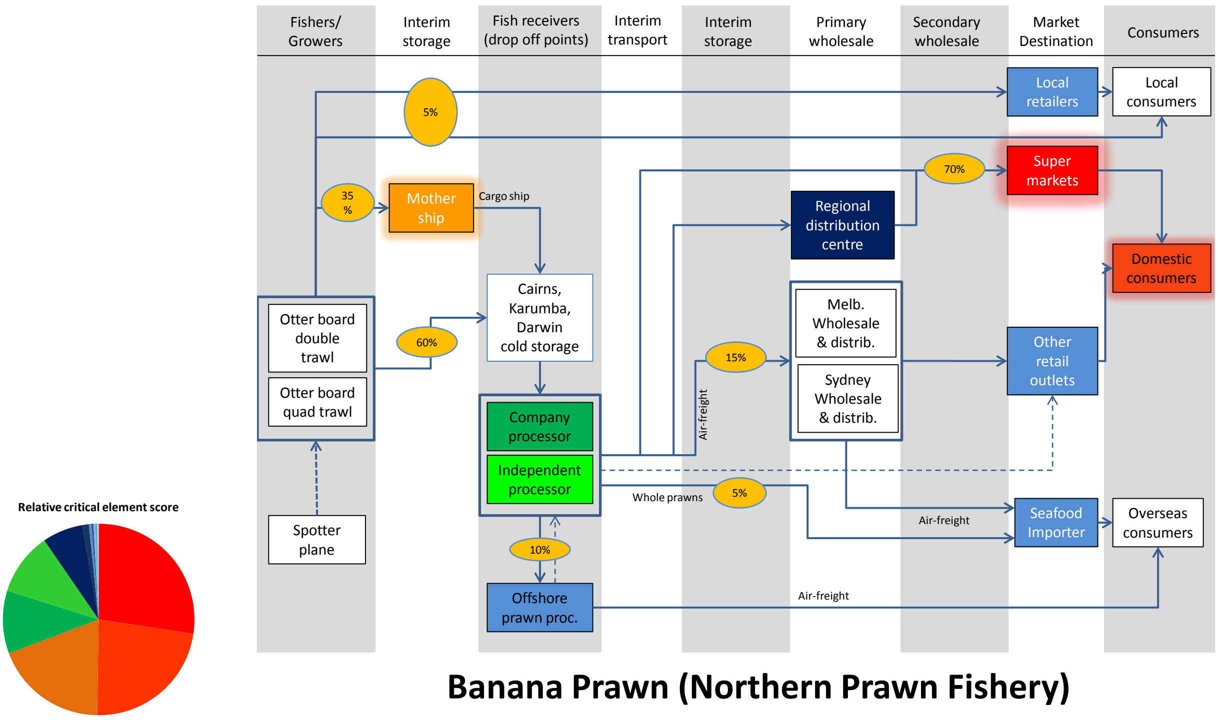
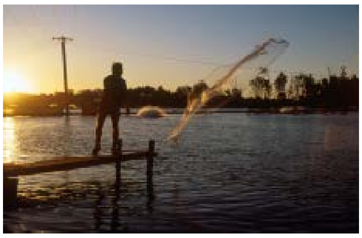
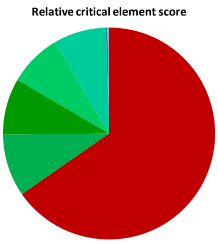


Figure 19 Banana prawn supply chain with colour coding to highlight key elements, with the relative distribution of these scores summarised in the accompanying pie diagram.

6. Aquaculture Prawn Supply Chain – critical elements



The Australian aquaculture prawn supply chain differed from the previous examples in that there was a single dominant key element, namely the domestic consumers (**Figure 20**). Hence attempts to increase the diversification (if not already the case) of the domestic consumer market will improve the stability of this supply chain.



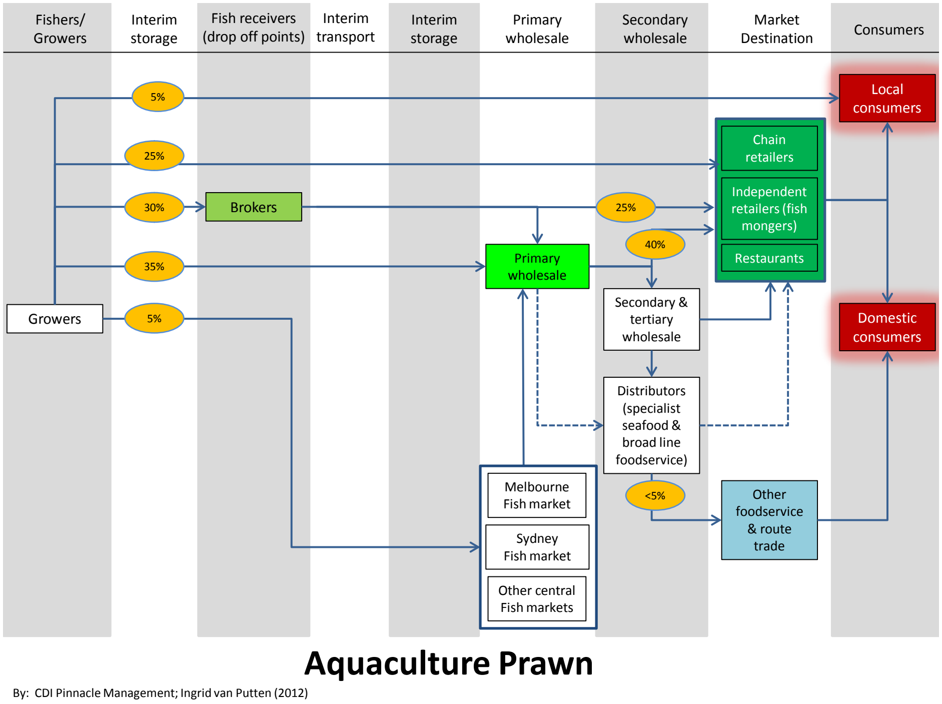
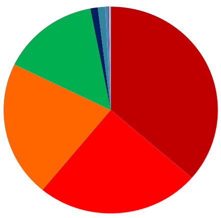


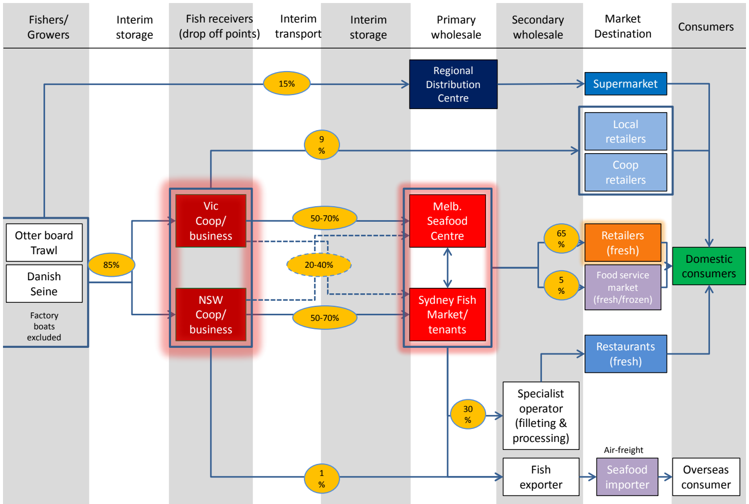
Figure 20 Aquaculture prawn supply chain with colour coding to highlight key elements, with the relative distribution of these scores summarised in the accompanying pie diagram.

7. Commonwealth Trawl Sector Supply Chain – critical elements

The critical elements identified by application of the SCI to the Commonwealth trawl supply chain were the Victoria and New South Wales Coop businesses and the Melbourne and Sydney markets (**Figure 21**). The fresh retailers were also identified as important elements in the chain. The supply-led nature of this supply chain suggests it may be more vulnerable than some of the other examples.

Relative critical element score





Commonwealth Trawl Sector

Figure 21 Commonwealth trawl supply chain with colour coding to highlight key elements, with the relative distribution of these summarised in the accompanying pie diagram.

8. Critical element summary for all case studies

A comparison of the supply chain quantitative metrics for each of the seven case studies is shown in **Table 10** and **Figure 22**. The WRL supply chain has the most elements and links, but the highest ratio of links to elements is seen for the banana prawn supply chain, suggesting it is highly connected. The most direct (lowest links:elements ratio) supply chain is the TRL (**Table 6**). The lowest and highest overall key supply chain index scores were for the banana prawn and oyster chains respectively. The top three key elements in each supply chain, as identified using the key supply indices for individual elements, differed across all the case studies, with the most common element being consumers (whether domestic or international). In general the key element in each chain was identified roughly equally as at the supply versus the demand end of the various supply chains (**Table 6**). Demand-led supply chains are generally considered preferable (Storey et al. 2006) and this analysis identified the TRL, WRL, banana prawn and prawn aquaculture supply chains as demand-led.

Lower overall SCI scores suggest a supply chain is more optimal in terms of being more diffuse and hence more stable. The banana prawn supply chain was found to have the lowest key supply metric as well as standardised metric whereas the Sydney rock oyster scored highest. The latter was the most linear of the supply chain networks, suggesting it has limited adaptive capacity. The extremely high individual scores for the two key elements in the oyster supply chain reinforce the high risk to the stability of this chain if one of these elements is perturbed. Of the three lobster supply chains, TRL had the lowest key supply metric, followed by WRL, with SRL scoring highest. The relatively greater stability of the TRL supply chain is evident too from the pie graph which shows a fairly even spread in the individual scores of the top few key elements, compared to a more critical dependence on three key individual supply chain elements for SRL. The standardised score for WRL is lower than for TRL which suggests that it rates more favourably (in the context of stability) than TRL if the large number of elements (WRL has the most elements and links) in this chain is taken into account.

Comparison of the distribution of the supply metrics across the different stages of the chain suggests some differences between supply chains (**Figure 22**). For example, key elements for the Sydney oyster supply chain are heavily skewed towards the supply end, whereas those for the aquaculture prawn example are skewed towards the demand end and the banana prawn example has a more even spread in terms of the distribution of key elements along the chain.

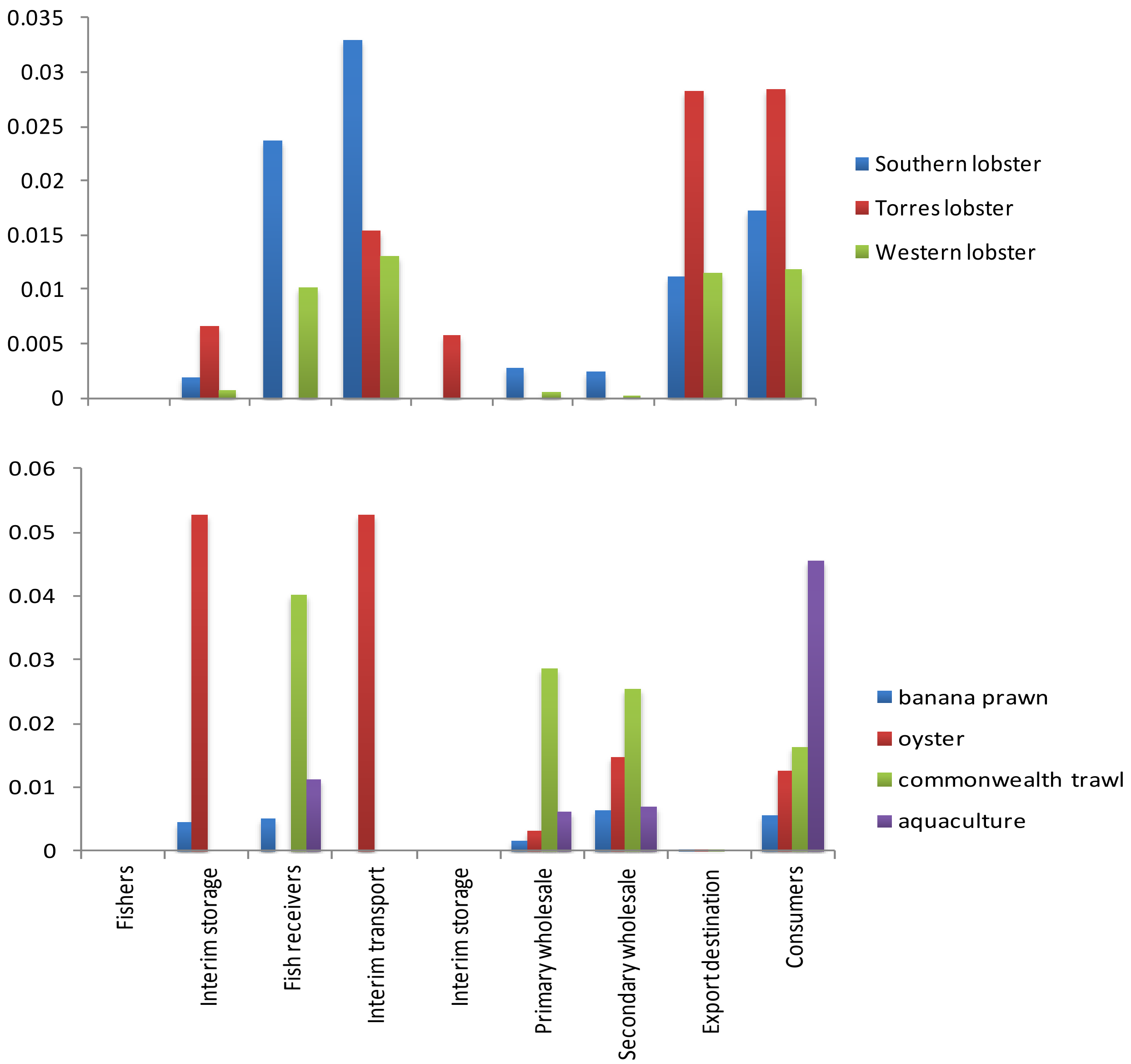


Figure 22 Plots of the standardised supply chain metrics aggregated over different stages of the supply chain to compare the distribution of key stages in each of the seven supply chain case studies. Note the two plots divide case studies with relatively different metric scores.

Table 10 Summary of key supply metrics for the seven case studies. In general a lower metric score represents a more stable and diffuse supply chain

SUPPLY CHAIN	NO. ELEMENTS	NO LINKS	RATIO LINKS/ ELEMENTS	KEY SUPPLY METRIC	METRIC (STANDARDISED)	KEY ELEMENT SUPPLY OR DEMAND END	TOP 3 ELEMENTS		
The southern rock lobster (SRL)	17	22	1.29	2.02	0.092	supply	Hobart airport	Processors	Chinese consumers
The tropical rock lobster (TRL)	15	16	1.07	1.35	0.084	demand	Chinese importer	Chinese consumers	US importer
The western rock lobster (WRL)	22	33	1.5	1.59	0.048	demand	Chinese consumers	Hong Kong importer	Processors (Geraldton)
Sydney rock oyster	13	19	1.46	2.58	0.140	supply	On farm storage	Ute/truck	Sydney/Brisbane
Banana prawn (NPF)	15	28	1.87	0.64	0.023	demand	Supermarkets	Domestic consumers	Mother ship
Commonwealth Trawl Sector	14	18	1.29	1.99	0.110	supply	Co-op business	Melbourne/Sydney markets	Retailers (fresh)
Australian Aquaculture Prawn	10	16	1.6	1.12	0.069	demand	Domestic consumers	Chain/independent retailers	Primary wholesaler

Critical elements: Implications for adaptation

Ensuring the resilience of critical elements in a chain may be particularly important in maintaining the longer term stability of a supply chain. For each sector, key findings are:

1. SRL: air transport is a critical element, and as an airport has limited flexibility to shift and adapt, emphasis should be placed on supporting and building the resilience of other critical elements such as the processors and Chinese consumers. For example, focusing effort on firmly establishing Chinese trade agreements may provide the most critical scope for growth and building stability in the SRL supply chain. At the other end of the supply chain, the processors are highlighted as important elements and hence the resilience of the chain can be strengthened by focusing interventions on building the stability of this component.
2. TRL: the key mechanism for stabilising this supply chain is to reduce uncertainty in supplying the Chinese and U.S. markets
3. WRL: Chinese consumers and associated Hong Kong importers are critical elements, followed by the Geraldton processors, and attention to ensuring these elements persist is important for this fishery.
4. SRO: The supply chain is highly linear at the supply end, with the interim storage and transport identified as critical elements - removal of either of the two critical elements would result in a collapse of the entire supply chain and failure to preserve connectivity. Broadening the supply base is a key adaptation need.
5. Wild prawns: supermarkets and the domestic consumers were identified as critical elements. It is important to secure a good working arrangement with the supermarkets. In general the banana prawn supply chain showed a relatively good spread of critical elements across the chain, and hence an ability to change and adapt connections in response to exogenous shocks.
6. Aquaculture prawns: an increase the diversity of the domestic consumer market will improve the stability of this supply chain
7. CTS: The supply-led nature of this supply chain suggests it may be more vulnerable than some of the other case studies, with the Victoria and New South Wales Coop businesses and the Melbourne and Sydney markets critical elements.

Overall: supply chains with more links and a balance of critical elements across the supply chain were considered as most stable. Improvement in supply chains can lead to overall growth and a reduction in the influence of critical elements that can disrupt product flow. Detailed discussion with stakeholders is now required to explore the range of options that exist for each of these critical nodes.

7.3 Objective 3 – Develop future models of supply chains to identify opportunities and barriers with regard to environmental change, biology, social and economic factors and Objective 4 – Develop strategies to overcome the barriers and take advantage of the opportunities

7.3.1 FUTURE SCENARIOS FOR THE SUPPLY CHAINS

Each case study was represented by two or three likely scenarios (**Table 11**) drawn from an initial and wider set of scenarios generated from project team discussions, literature review, initial stakeholder interviews and related projects. These scenarios were kept general, and were considered to occur over the next two decades to the 2030 time period. These scenarios were used to inform the stakeholder interviews (**Section 7.3.2)** and LCA interpretations (**Section 7.3.3**).

Table 11 Scenarios explored for assessing the impacts on case study supply chains.

FISHERY	SCENARIO
SRL	**Supply change** Continued large scale declines in recruitment across SE Australia leading to further stock size reductions in north and NE in particular, but also west and SW. **Demand change** Sudden and prolonged market closure due to any of the following reasons: illegal access routes closed, taxing issues, quality controls and import restrictions (SARS, disease, HAB).
WRL	**Supply change** Continued large scale declines leading to stock size reductions along the entire west coast. **Demand change** Sudden and prolonged market closure due to any of the following reasons: illegal access routes closed, taxing issues, quality controls and import restrictions (SARS, disease, HAB).
TRL	**Supply change**. Small islands are impacted by sea level rise consequently shifting islander population. Fishers will have to travel further to reach the previous catching grounds causing higher travel costs to islander fishers. There also will be increased pressure on more easily accessible (closer) reefs causing localised depletion in the fishery. The overall effects will be decreased supply due to lower catches from previous grounds (due to increase fishing cost) and lower catches from closer grounds due to localised depletion). **Demand change** Increased international competition due to change in geographical spread of production with PNG increasing production (wild catch). TRL is also increasingly cultured in Asian countries increasing competition and putting downward pressure on price (as it is an inferior quality product – but consumers do not differentiate between wild and cultured TRL) (fished and cultured). Overall there is increased international competition from both non-Australian wild and farmed product increasing quantities available and reducing average prices
SRO	**Supply change** Extreme weather events (e.g. floods occurring in SE Australia) lead to closures of lease due to i) run-off pollution form acid sulphate soils caused by upstream farming activities, ii) fresh water flooding which leads to the dilution of saline water, iii) disease outbreaks, and iv) algal blooms. **Demand change** Consumer demand for oysters slowly decreases due to a perception of contamination of oysters in coastal areas of eastern NSW
Banana prawns (wild)	**Supply change** Long term trend to higher floods and wetter summers increase recruitment, growth and migration to fishing grounds **Demand change** Long term increase in competition from imported and farmed prawns
Aquaculture prawns	**Supply change** <u>Positive effect</u>: Changes in production. SRL and increased flooding regimes with a net increase of suitable (extent & condition) aquaculture habitat <u>Negative effect:</u> Increase in extreme events (cyclone, flooding, heat and frequency and/or nature/type of diseases) affecting

	ponds and prawns. **Demand change** Increase competition as a result of cheaper imports & higher supply from wild-caught banana prawns
CTS	**Supply change** A gradual change in the distribution of key species to the south as a result of warming eastern Australia waters **Demand change** Increased supply of similar seafood from international markets, from other areas less affected by climate change, leads to increased competition in the domestic market

The scenario space that was covered for the future scenarios to guide each of the fishery case studies is shown in **Table 12**. For example, the scenarios explored for SRL were a supply-driven slow change in abundance and a shock at the consumer end of the supply chain. All scenarios were evaluated for at least one fishery (one case study in each column and row of **Table 12).**

Table 12 Scenario space for future supply chains.

		IMPACT AT THE "SUPPLY" END OF THE CHAIN (LEFT HAND SIDE) (CLIMATE CHANGE KEY TO THE SCENARIOS)		
		Slow change in abundance	Shock change in abundance	Slow change in distribution
IMPACT AT THE "CONSUMER" END OF THE CHAIN (RIGHT HAND SIDE) (CLIMATE CHANGE LESS OBVIOUS BUT IMPLICIT)	Shock (market closure or change)	SRL WRL		
	Slow change in preference		SRO	
	Slow change in market/competition	Prawns (wild) Prawns (aqua)		TRL CTS

Future scenarios: Implication for adaptation

- Not all combinations were realistic for each case study, and so a subset of scenarios (2-3) was examined in each case.
- These scenarios were used in subsequent sections to explore adaptation options

7.3.2 SOCIAL PERCEPTION ANALYSIS – FINAL INTERVIEWS

The impact of these future scenarios was evaluated with stakeholders in interviews. The results of these future interviews with 16 stakeholders undertaken by one of the project team (L. Lim-Camacho) are presented in the following subsections for each fishery. Codes related to comments are retained for research purposes in this version of the report. For each scenario, general responses are described, followed by the implications with regard to adaptation for the overall supply chain, particular elements in a supply chain, or from a policy or governance perspective. Not all categories were identified for adaptation. Additional results are available in Lim-Camacho et al. (Paper 7).

1. Southern Rock Lobster – Tasmanian sector

A total of three stakeholders were presented with one future supply scenario and one demand scenario for the southern rock lobster fishery during telephone interviews. These stakeholders represented fishing, fishery management and science sectors, and were asked, given their background, what they felt were the impacts of change on the supply chain. This included a discussion on key sectors of the chain likely to be affected by the change, as well as potential adaptation options.

SCENARIO 1

Potential negative supply change: Continued large scale declines in recruitment across South Eastern Australia leading to further stock size reductions in north and northeast in particular, but also west and southwest.

Fluctuations in recruitment rates have been experienced in South Australia and Tasmania for the last five years, thus stakeholders believe that the industry is familiar with the types of responses required to manage such situations. Often, the expected interactions of demand versus supply have allowed fishers and processors to cope with fluctuations in stock. However, such responses seem to be reactive and focused on the short term, rather than considered, strategic actions, resulting in a redistribution of profits and value along the chain, as opposed to an increase in the combined competitiveness of businesses. A key point in the adaptation options identified by stakeholders is that often, a response employed in one stage of the chain impacts on how the rest of the chain responds. This reinforces the importance of looking across the supply chain when considering adaptation strategies.

<u>Governance adaptation:</u>

- Reduction of total allowable catch (TAC) to manage stocks *(efficiently managing resources, ensuring long term sustainability)* SRL_8

<u>Lease owner adaptation:</u>

- Reduction of lease prices to encourage alternative income stream as opposed to relying on product income *(responding to opportunities, resilience)* SRL_8

<u>Fisheries adaptation:</u>

- For lease owner fishers, managing income streams to identify higher returns on investment, i.e. leasing in to other fishers to encourage income from leases as opposed to income from fishing (during times when catch rates are low) *(responding to opportunities, resilience)* SRL_8
- As a result of reduced lease prices, increase in number of temporary fishers to take advantage of short term improvement in profit margins *(responding to opportunities)* SRL_8, SRL_9

> "In the years where the TAC dropped, fishers still couldn't catch the TAC. We saw an increase in the number of boats fishing because people saw a short term business opportunity." SRL_8

- Manage catch efficiency and price to lease ratio to arrive at optimum operating cost and profit margin *(responding to uncertainties and opportunities)* SRL_9

> "If the stock is getting healthier, if there is an increase in recruitment and the catch rates go up, you tend to see businesses leaving...because it means that there's fewer days required to take the same amount of catch. Conversely if the stock is declining, then you need more days to take the same amount of catch and that creates economic processes which sucks more businesses into the system." SRL_9

- Fishers shift to other areas to compensate for stock reductions in their preferred fishing areas *(responding to uncertainties)* SRL_7

SCENARIO 2
Potential negative demand change: Sudden and prolonged market closure due to any of the following reasons: illegal access routes closed, taxing issues, quality controls and import restrictions.

The impact of a sudden and prolonged market closure, specifically in China, is considered by stakeholders as potentially catastrophic, considering the reliance of the industry on the Chinese markets as the main destination for southern rock lobster exports.

> "So in the short term that affects the catching sector and the processing sector's cash flow. If that situation was in the longer term then both would be significantly affected because China, as a market, is currently 90% of where all the fish goes. And there is no other immediate market to switch that amount of volume into." SRL_8

<u>Short term supply chain adaptation:</u>

- Processors respond to increasing stock levels (as a result of inability to market products) by dropping beach prices, as a disincentive for fishers *(efficiency, responding to uncertainties)*. This leads to fishers temporarily discontinuing fishing, until the market is opened or alternative markets are accessed. SRL_8

<u>Long term supply chain adaptation:</u>

- Develop partnerships with customers in destination market, to identify reliable pathways for market entry *(responding to uncertainties, increasing capability)* SRL_7

<u>Marketing adaptation:</u>

- Diversify markets to domestic and other international markets, to reduce reliance on individual markets (i.e. China) and spread risk. This would require a process of developing such markets to a level where returns are similar, if not comparable, to current returns gained from existing markets. *(responding to opportunities, increasing capability)* SRL_8, SRL_7

> "Theoretically it would be much safer for the industry if they had 20% of their products going into the domestic market and to get a price that they could be profitable with and 10% is going to India, 10% is going to Malaysia, 10% is going to Indonesia and Singapore and only 40% is going into China. To me it would be about spreading the risk in having a major market failure in any one particular country." SRL_8

2. Tropical Rock Lobster

A total of four stakeholders were presented with one future supply scenario and one demand scenario for the tropical rock lobster fishery during telephone interviews. These stakeholders represented fishery management, processing, conservation and science sectors, and were asked, given their background, what they felt were the impacts of change on the supply chain. This included a discussion on key sectors of the chain likely to be affected by the change, as well as potential adaptation options.

SCENARIO 1

Potential negative supply change: Small islands are impacted by sea level rise consequently shifting islander population. Fishers will have to travel further to reach the previous catching grounds causing higher travel costs to islander fishers. There also will be increased pressure on more easily accessible (closer) reefs causing localised depletion in the fishery. The overall effects will be decreased supply due to lower catches from previous grounds (due to increase fishing cost) and lower catches from closer grounds due to localised depletion).

The structure of the tropical rock lobster fishery having two types of fishers (traditional inhabitant and non-traditional inhabitants) operating distinctly from each other indicates that the impact of the abovementioned change will also vary significantly. Given the relatively small area in the Torres Strait, the non-traditional inhabitant fishers are seen to be minimally impacted by an increase in sea levels, given that they have the infrastructure to travel further (larger boats). On the other hand, traditional inhabitant fishers can be highly impacted by this change, as they often do not have the infrastructure and processes to engage in fishing further distances. TRL_1

Supply chain adaptation:

- Vertically integrate along the chain to manage risk of fluctuating supply, and improve agility and flexibility in order to continue to respond to market needs. *(Improving capability, agility)* TRL_30

Fisheries adaptation

- As a result of increased costs of operations, fishers who are currently supply tails may diversify into the live product market to capture more of the consumer dollar through a higher value product *(responding to uncertainties and opportunities)* TRL_4

  "If it were going to cost some more to fish it, they might need to seriously look at changing their management practices to chase a higher market." TRL_4

- Invest in boats capable of fishing longer distances, changing the structure of the fleet and operations (longer fishing times) to enhance return on investment and encourage efficient operations *(responding to opportunities, improving efficiency)* TRL_4

  "So it may actually in a perverse way encourage them to become more efficient and more cognitive of market opportunity and the opportunity is clearly in live lobster, it's worth a lot more than tail market, which is easier to fish for and easier to do, but it's not realised in returns available from resource and that's demonstrated very much by the white fellow fishery up there." TRL_4

- To manage localised depletion, some fishers can move to other areas, such as east coast of Queensland, to sustain product supply *(responding to uncertainties)* TRL_30

Marketing adaptation:

- Diversify product range to include live lobsters, in order to catcher more of the consumer dollar and improve returns on investment given the increase in operation costs *(responding to opportunities)* TRL_4

SCENARIO 2

Potential negative demand change: Increased international competition due to change in geographical spread of production with PNG increasing production (wild catch). TRL is also increasingly cultured in Asian countries increasing competition and putting downward pressure on price. Overall there is increased international competition from both non-Australian wild and farmed product increasing quantities available and reducing average prices.

Stakeholders are fairly positive about the ability of the industry to cope with an increase in competition from aquaculture in Asia and wild catches in PNG. Firstly, some believe that in the short to medium term, aquaculture in Asia and catches in PNG are not going to be a significant threat as they do not have the support (science and governance) to push the industry further (TRL_1, TRL_2, TRL_4). Secondly, the market for tropical rock lobsters is considered to be quite large (i.e. China), that an increase in supply from competitors will not result to a loss of current markets from Australian tropical rock lobsters (TRL_30).

Supply chain adaptation:

- Improve efficiency in supply chain operations to minimise unnecessary handling and transport of product (i.e. two processor steps in the chain) in order to compete more effectively. *(Improving efficiency)* TRL_1

Marketing adaptation:

- Build good working relationships with customers in existing major markets, to maintain high value status of product and ability to supply to customers once market access has been regained *(responding to uncertainties through agility and resilience, increasing capability to sustain competitive advantage)* TRL_30
- Build on expanding consumer market as developed by increase in cheaper product (aquaculture), possibly through promotion, consumer education, and developing relationships with customers in destination markets *(responding to opportunities, increasing capability)* TRL_2

3. Sydney rock oysters

Two stakeholders were presented with one future supply scenario and one demand scenario for oyster fishery during telephone interviews. These stakeholders represented fishing and marketing sectors. As with the other fisheries, the stakeholder were asked what they felt were the impacts of change on the supply chain, and how they envisaged the oyster supply chain to adapt to such changes.

SCENARIO 1

Potential negative supply change: Extreme weather events (e.g. floods occurring in SE Australia) lead to closures of lease due to i) run-off pollution form acid sulphate soils caused by upstream farming activities, ii) fresh water flooding which leads to the dilution of saline water, iii) disease outbreaks, and iv) algal blooms.

The Sydney rock oyster fishery has been exposed to recent events that mirror the above scenario, with extreme weather events leading to flooding and the temporary closure of leases as a result. The key concern for members of the industry is the frequency to which such events would occur – businesses would not be able to cope if supply was interrupted frequently and customer trust would be eroded over time, limiting the ability of fishers to re-establish connections once supply resumes.

Supply chain adaptation:

- Invest in research addressing disease resistance, to manage the impacts of pollution and minimise impact on supply *(responding to opportunities, resilience)* SRO_10

Fisheries adaptation:

- Through improvements in oyster disease resistance research, grow oysters that are more resilient to less-than-ideal growing conditions *(increasing capability, responding to uncertainties)* SRO_10
- Consider a shift from intertidal to sub-tidal production, to build resilience from flooding as well as manage impacts of extreme temperatures currently experienced in intertidal production. This adaptation however, is seen as quite costly and is considered a transformation for the industry which could result to some growers leaving rather than making the change as areas for sub-tidal production are limited. *(responding to uncertainties, resilience, increasing capability)* SRO_10

> "I think it would be too large a structural change to alter the way that the industry works, from an infrastructure point of view, but they could move from intertidal production to sub tidal. It's far too large a change, and what would happen is that the industry would just recede. There are a number of sub tidal operations at the moment, which could withstand serious flood and could withstand some of the extreme temperatures they're experiencing in intertidal culture, but there's just simply not that much water available for the industry to move to a sub tidal culture." SRO_10

- Establish leases in areas that are less vulnerable to extreme events *(responding to uncertainties)* SRO_28

Marketing adaptation:

- Customers substitute using Pacific oysters to sustain consumer demand and maintain consumer interest in oysters in general, enabling to re-introduction of Sydney rock oysters when supply resumes *(responding to uncertainty)* SRO_10, SRO_28

SCENARIO 2

Potential negative demand change: Consumer demand for oysters slowly decreases due to a perception of contamination of oysters in coastal areas of eastern NSW.

The Sydney rock oyster fishery has also experienced several disease outbreaks in the past that have led to a change in consumer perceptions, not only of oysters, but also of seafood in general. The 1997 outbreak of Norwalk virus gastroenteritis associated with the consumption of raw oysters has been highlighted as an example of how such a scenario would once again affect the industry (SRO_10).

<u>Governance adaptation:</u>

- Have a trusted statutory authority educate consumers of the real risks of consumption, through a series of press releases and information campaigns to overcome any misleading information that could lead to further declines in demand *(responding to uncertainties, improving capability)* SRO_10
- Encourage the role of food safety authorities, such as the Australian Shellfish Quality Assurance program, to ensure that consumers are protected from future outbreaks that can impact on long term perceptions of the product *(responding to uncertainties, improving capability)* SRO_10, SRO_28

<u>Marketing adaptation:</u>

- Engage in a publicity campaign to inform consumers of the effects of different types of environmental conditions to human health (i.e. algal bloom, viruses, etc), to support governance adaptation above *(responding to uncertainties, improving capability)* SRO_28

4. Wild banana prawns – NPF sector

Three stakeholders from the banana prawn fishery (NPF sector) were consulted, each presented with one future supply scenario and one demand scenario. These stakeholders represented science, policy and processing sectors and were asked, given their background, what they felt were the impacts of change on the supply chain. This included a discussion on key sectors of the chain likely to be affected by the change, as well as potential adaptation options.

SCENARIO 1

Potential positive supply change: Long term trend to higher floods and wetter summers increase recruitment, growth and migration to fishing grounds.

Stakeholders have mixed responses to a potential increase in supply of banana prawns, with some feeling that demand is currently able to meet this increase, while others believe that it will oversupply the market. A key concern for stakeholders is a decrease in price as the volume of product in the market increases. As such, participants in the supply chain who deal with higher volume turnover are the ones who are more likely to benefit from such a change. Smaller fishing operations, limited by their infrastructure, are unlikely to take advantage of this opportunity unless an effort is made to increase their capacity to fish higher volumes of banana prawns. WP_5, WP_23

> "The opportunity may not be the opportunity the Australian fishing industry wants." WP_5

<u>Fisheries adaptation:</u>

- Improve catching facilities to cope with increased volume of supply to take advantage of increased supply, combined with improved storage options for catch *(improving capability, responding to opportunities, agility)* WP_26b

Storage adaptation:

- Improve storage facilities to cope with increased volume of supply during catch season, allowing for product to be marketed at other times of the year in order to maximise value and reduce the risk of oversupply. *(improving capability, responding to opportunities, agility)* WP_23, WP_26b

Marketing adaptation:

- Secure existing local markets by developing relationships with local customers and encourage consumption of locally-captured prawns *(improving capability and efficiency, responding to opportunities)* WP_5
- Set up contracts with customers to promote banana prawns to encourage demand and facilitate product turnover during times of high volume supply *(responding to opportunities)* WP_5
- Promote Australian banana prawns more widely to encourage increase in consumption through effective marketing campaigns *(responding to opportunities)* WP_23

> "I guess these things can be heavily influenced by effective marketing campaigns. And if we're subject to strong marketing, we might all find ourselves eating a lot more prawns. I mean that'd be great, I love eating prawns." WP_23

SCENARIO 2

Potential negative demand change: Long term increase in competition from imported and farmed prawns.

An increase in competition from imported and farmed prawns is seen as a threat by stakeholders, primarily because they believe that it will further reduce the selling price of banana prawns as consumers shift to cheaper, imported product. Some stakeholders believe that this would lead to the industry contracting, with smaller, less efficient operations not being able to sustain their business. WP_23

Fisheries adaptation:

- Fishing operations strive to become more efficient, through the use of faster, more efficient vehicles, leading to more professional, commercial operations *(improving capability, improving efficiency)* WP_23

Marketing adaptation:

- Promote consumption of locally-sourced product, minimising transportation and storage and placing a higher value on origin of produce, through sustainable seafood campaigns jointly with retailers and restaurants *(improving capability, improving efficiency, responding to opportunities)* WP_5, WP_26b

> "The more that we can consume naturally in our local geographic areas without having to come under sufferance of freighting goods and cold storing for long periods of time, the better the effect not just for the now, but also for the later as we potentially see." WP_5

5. Aquaculture Prawn

A total of four stakeholders were presented with two future supply scenarios and one future demand scenarios for the aquaculture prawn industry during telephone interviews. These stakeholders represented farming, marketing and policy sectors in the supply chain, and were asked, given their background, what they felt were the impacts of change on the supply chain. This included a discussion on key sectors of the chain likely to be affected by the change, as well as potential adaptation options.

SCENARIO 1

Supply change: Increased flooding regimes resulting to a net increase of suitable aquaculture habitat

Sea level rise along the Queensland coast is expected to result to some areas of agricultural land becoming marginalised, especially where sugar cane is grown. This is seen as an opportunity by some stakeholders to potentially expand aquaculture in such areas, where certain levels of salt water intrusion is seen as more tolerable compared to other crops. On the other hand, increased flooding in aquaculture areas as a result of prolonged heavy rainfall is seen as a detriment for farming operations, with the potential to result to ponds overflowing and product loss, as well as damage to on-farm infrastructure.

Fisheries/Production adaptation:

- Expand areas where prawns can be farmed in response to other farming industries moving due to rising sea level *(responding to opportunities presented, adaptation)* AP_A1
- Set up ponds in flood-free areas and reinforcing low areas to minimise risk of loses *(minimise risk presented by an uncertain future, thus increasing resilience)* AP_A1
- Expansion of farms to take advantage of increase in suitable habitat, tapping into current perceived unmet demand for prawns domestically *(responding to opportunities presented, becoming more competitive and profitable)* AP_20

Marketing adaptation:

- Improved marketing communication domestically to support increase in supply of domestically farmed prawns and effectively compete with imported product *(respond to opportunities)* AP_20

Governance adaptation:

- Adjust flood marks to protect farms from losses and flood-proof farms *(minimise risk and increase resilience)* AP_20

SCENARIO 2

Negative supply change: Increase in extreme events (cyclone, flooding, heat) affecting ponds and prawns.

An increase in extreme events affecting areas where prawns are farmed and distributed is seen by stakeholders as a concern for the supply chain. Primary concerns are a disruption in power supply, affecting pond operation and on-farm cold storage, as well as a disruption of transport routes, which can impact on the inbound flow of farm supplies (feed, fuel) and outbound flow of product to markets. In addition, periods of prolonged rainfall and extended periods of above or below average temperatures also impact on farm operations and product quality.

Overall supply chain adaptation:

- Encourage innovation that leads to more efficient operations, reliable input supply (power mainly) and more resilient infrastructure supporting farming and logistics, such as higher capacity solar panels, improved aeration technology, and better infrastructure *(Improving capability, resilience and agility)* AP_A1

Fisheries/Production adaptation:

- Proactively seek information to be able to forecast future weather patterns *(adaptation)*, to inform resilience strategies, such as: destocking to minimise losses from extreme events and investing in power generation in case of disruptions, (i*ncreasing capability to manage risks posed by external environment),* and changing stock levels to take advantage of opportunities presented by expected average temperatures for a season *(increasing capability to take advantage of opportunities)* AP_20

> "I know some farms have tended to de-stock and not grow as many prawns if they are expecting a season to be bad...if the three-monthly forecast is looking bad in terms of extreme weather they may only stock up half the farm." AP_20

> "Use the available weather information, that would allow them to forecast what the temperature is going to be like for the coming season, which would then tell them how many tonnes of prawns they would ultimately get, how many tonnes of feed they'd need to have ordered. It would tell them if they were going to have a good season with a lot of growth or a poor season with slow growth." AP_20

- Reduce pond levels during periods of heavy rainfall *(increase resilience, agility)* AP_21
- Have back up power sources, to enhance reliability and minimise losses in response to uncertainties brought about by extreme events (power disruptions) *(reliability, responding to uncertainties of the environment)* AP_A1
- Ensure access to infrastructure, such as locating farms close to main roads, to limit impacts of being cut off from major transport lines *(responding to uncertainties through agility and resilience)* AP_18

Storage and logistics adaptation:

- Shift location of cold storage facilities closer to markets and in areas more resilient to impacts of extreme weather events, ensuring delivery of product to market and protection from stock losses *(efficiency, agility, resilience)* AP_20
- Improve and protect logistical routes to ensure continuous operation, reliability of supply and reduction in disruptions *(resilience)* AP_18

> "One thing I think that the government can do is actually ensure that the freight route and be it train and road are in a certain state where they're not going to be impacted and shut by these extreme events because realistically they're the lifeline of stock feed and fuel up and down the coast." AP_18

Marketing adaptation:

- Proactively seek information on climate and seasonal forecasting to identify suppliers able to meet ongoing demand *(agility, resilience)* AP_20

> "So I guess maybe they [wholesalers] are the people who are going to be thinking about, next year is going to be an El Nino, there's not going to be a lot of prawns floating around, so how am I going to – where am I going to get my prawns from?" AP_20

SCENARIO 3 Potential negative demand change: Increase competition by cheaper imports & higher supply from wild-caught banana prawns

Stakeholders have a view that the market for prawns in Australia is under-served, and that there is room to grow this market significantly. As such, the impact of more product being available in the market is not a significant concern, though it suggests that the firms in the sector may have to do things differently in order to compete effectively.

Fisheries/Production adaptation:

- Grow larger prawns than imported product to establish market differentiation and advantage *(responding to opportunities)* AP_20

> "Our central issue is that we need our prawns to be big, so they have to grow fast to get to enough size that clearly demarcates them from the imported prawns, which tend to be very small." AP_20

- Grow prawns more intensively by increasing productivity (prawns per cubic metre), reducing costs and achieving economies of scale *(increasing capability and efficiency)* AP_20
- Potential departure of less competitive farming operations *(sector efficiency)* AP_A1

Marketing adaptation:

- Promote locally grown and caught prawns in domestic market to increase value of, and improve demand for, Australian product, in comparison to imports *(responding to opportunities, responding to uncertainties, resilience, increasing capability)* AP_A1

Governance adaptation:

- Encourage investment into aquaculture to ease the need to import to meet consumer demand for prawns *(responding to opportunities)* AP_A1

6. Summary of adaptation options across fisheries – stakeholder interviews

In response to the future scenarios, a wide range of adaptation options, across the supply chain were identified by the stakeholders. A qualitative summary of the adaptation options in different stages of the supply chain is shown in **Table 13**. As with the initial interviews (**Section 7.2.2**), adaptation options were concentrated at the production end of the supply chain.

Table 13 Summary of the range of adaptation options identified by stakeholders in each of the five sectors (H = many adaptation options identified, L = limited adaptation options identified).

SECTOR	WHOLE OF CHAIN ADAPTATION	FISHERIES ADAPTATION	PROCESSING ADAPTATION	LOGISTICS & STORAGE ADAPTATION	MARKETING ADAPTATION	GOVERNANCE ADAPTATION	COMMENT
Aquaculture prawns	L	H		L	L	L	A key adaptation pathway for aquaculture prawns is the continuation of innovation and science progress in aquaculture, which will allow farming to be more efficient and sustainable.
Wild prawns		L			H		Sustainable marketing is a key adaptation option for wild-caught banana prawns, encouraging consumers to buy local, resulting to a sustainable, high value industry that is able to compete with imported product.
Southern rock lobster	L	H			L		Short term options receiving most attention at this time.
Tropical rock lobster	L	L			L		Adaptation options for TRL, especially for the traditional inhabitant fishers, are limited by potentially contradictory economic and social goals.
Sydney rock oysters	L	L			L	L	The oyster fisheries sector has multiple adaptation options available, but some of these involve high capital costs and require transformative change.

Final interview: Implication for adaptation

- The stakeholders were well informed regarding potential future scenarios, and were able to propose a range of adaptation options.
- Adaptation options were predominately at the supply end of the supply chain, and tended to be short term options.
- These options were used to evaluate the future LCA evaluation
- Additional work to explore these options with integrated modelling is warranted (see **Section 9**).

7.3.3 LIFE CYCLE ASSESSMENT OF FUTURE SCENARIOS

A limited set of the future scenarios for each fishery that had a LCA were evaluated in combination with some of the adaptation options proposed to determine the outcome with regard to the environmental indicators.

1. Southern Rock Lobster LCA future scenarios – Tasmanian component

Continued large scale declines in recruitment across SE Australia leading to further stock size reductions in north and NE in particular (**Scenario 1**) may lead to a decrease in CPUE in the short term. The decrease in efficiency in the fishery would increase the footprint of the SRL across all indicators. The result may be that the contribution of the capture stage to global warming potential and cumulative energy demand would outweigh the contribution from air transport. However, as the fishery is managed with the aim of a stable CPUE, eventually the TACC would be reduced in line with abundance changes. In the longer term the large scale recruitment declines may therefore lead to a reduction in the TACC which could cause operators to exit the industry thereby reversing the above impact on global warming.

The impact of sudden and prolonged market closure would change the environmental footprint of the SRL as the airfreight stage, which is responsible for over half of the carbon footprint and energy use, would be removed. If local sales were to replace international sales the carbon footprint of the SRL at wholesale would therefore be significantly reduced. The degree to which other adaptations to this scenario, including freezing, value adding or holding live lobsters for longer periods, would alter the footprint of the SRL could also be modelled through LCA. Marine ecotoxicity and eutrophication would be unlikely to change as the impacts are mainly at the market end of the supply chain and the contribution of the capture in effect does not change.

2. Wild Banana Prawn LCA future scenarios – NPF sector

The life cycle impacts of increased recruitment following a long term trend to higher floods and wetter summers may be a reduction in carbon emissions, energy use and eutrophication at the capture stage per kilogram of prawn due to improved efficiencies in the fishery. These improvements at the capture phase of the fishery may lead to improved efficiency at other stages of the supply chain. However, the overall footprint of the banana prawn industry would likely increase, despite the greater CPUE at the capture phase, as more product is transported and processed.

On the other hand, a long term increase in competition from imported and farmed prawns could result in fishers leaving the industry and less catch being taken. The decrease in catch would decrease efficiency in the fishery as well as at storage, processing and wholesale.

3. Commonwealth Trawl Sector LCA future scenarios

A gradual change in the distribution of key species to the south as a result of warming eastern Australia waters may lead initially to increased fuel use by boats as they travel further from home ports in NSW and Victoria. The relative contribution of the transport phase to the overall footprint of the CTS fishery may also increase as fish will increasingly need to be driven or flown from ports in the south to major market in Melbourne and Sydney. In the long term, home ports may shift south reducing the amount of travel required to capture and land fish thus reducing the footprint.

Increased supply of similar seafood leading to increased competition in the domestic market may result in fishers leaving the fishery and a reduced catch from the CTS. A smaller fleet could in fact result in a higher CPUE as fewer boats will be competing to catch the fish. Should this be the case fishery fuel use will fall and lead to a smaller footprint per kilo of fish caught at the capture phase in the CTS.

4. Tropical Rock Lobster LCA future scenarios - Torres Strait sector

Two adaptation scenarios were analysed in a quantitative manner (see van Putten et al, Paper 2). The first scenario relates to the TRL only whereas the second scenario relates to both the SRL and TRL. The first scenario is an autonomous adaptation that is implemented to reduce costs and climate change impacts of the fishery. In this scenario the status quo with respect to abundance of TRL is assumed and thus there is no change in TRL abundance due to climate change.

In the first scenario the TRL fishery implements an autonomous adaptation to reduce costs and climate change impacts in the last phase of the supply chain. It is assumed that the fishery can reduce freighting by changing the freighting route of live TRL product from processor to market. We modelled an option whereby all live TRL product bypassed Cairns airport and flew direct out of Horn Island to the final destination in China, thus reducing flying distance. We acknowledge that this airport could not currently handle the size of the airplanes capable of such international flights, and so this scenario is intended to be indicative of delivering product via a more direct supply route.

When implemented in the LCA analysis the reduction in flying distance is estimated result in a fall in the contribution to global warming for the commercial live TRL catch by 2.14 kg CO_2 per kilo of lobster product in the last phase of the supply chain (due to the change in the flight distance from processor to market – **Figure 23**). The contribution to global warming is now estimated to be 11.62 kg CO_2 per kilo of lobster product for the commercial non-indigenous sector (a saving of 490 t CO_2 per year) and 13.06 kg CO_2 per kilo of lobster product for the commercial indigenous sector (a reduction of 109 t CO_2 per year).

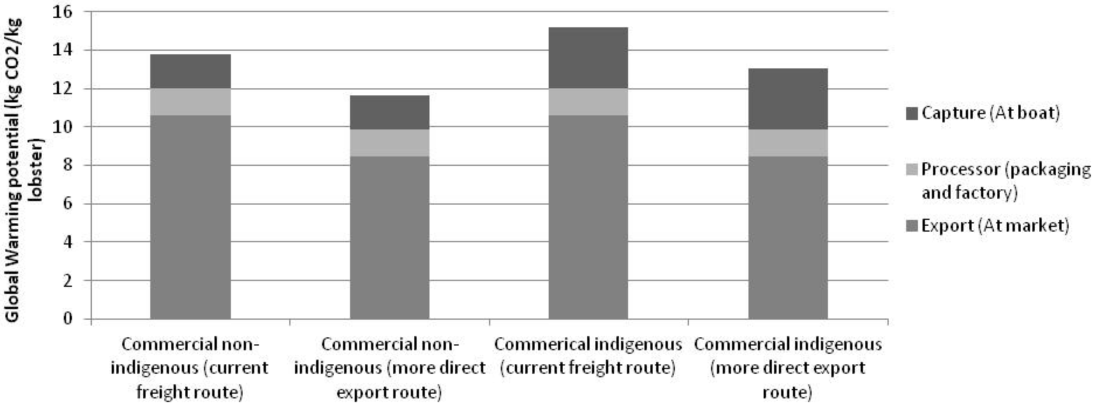


Figure 23: Global warming potential for four TRL product and fisher types.

Cumulative energy demand for the TRL live product fishery is also estimated to fall by 24% (52.74 MJ LHV per kilo of lobster) for the non-indigenous sector and 10% (33 MJ LHV per kilo of lobster) for the indigenous sector.

In the second scenario there is an assumed climate change induced abundance change in both the SRL and TRL fisheries. We focus on a 20% reduction in abundance but this adaptation scenario could also relate to an abundance increase, in which case the result would be linearly the opposite. In this scenario the relative LCA implications and impact at the fishery level are compared and the adaptation option is simply that the capture sector adapts by a reduction in the number of fishers. The total catch for the SRL is currently 1,222 tonnes and for the TRL total catch is 704 tonnes. A 20% climate change induced abundance reduction in both fisheries in will have a linearly related effect on the contribution to global warming but 17% of this reduction will be caused by contraction of the size of the SRL fishery and only 3% from a smaller size TRL. The reduction in the contribution to global warming would be proportional throughout the supply chain.

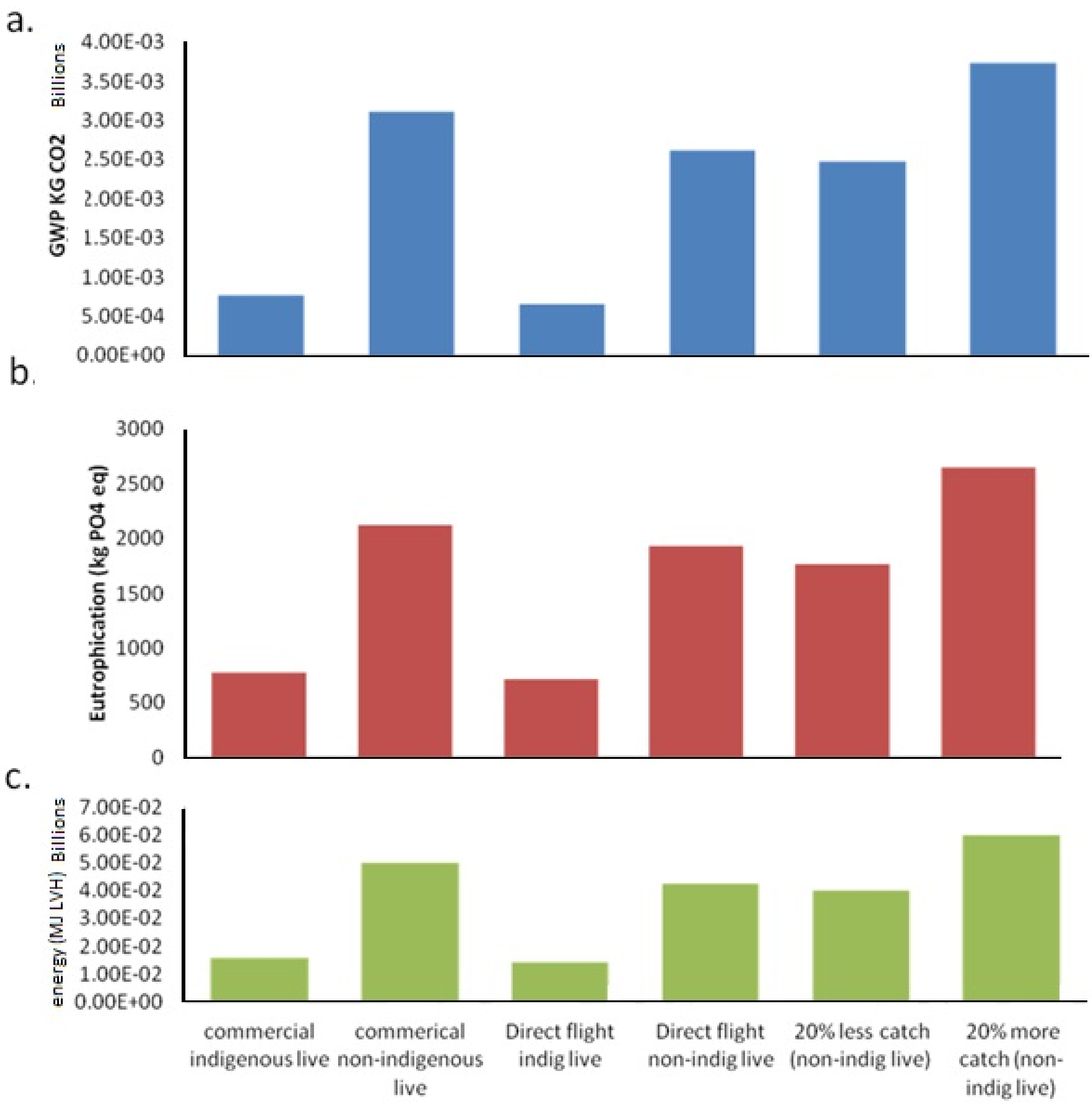


Figure 24. LCA outputs of the tropical rock lobster fishery for the entire catch for two dominant fisher typologies (commercial indigenous live, and commercial non-indigenous live) (column 1 and 2 – status quo) and three future scenarios (direct flights from Horn Island to China for export for commercial indigenous live, and commercial non-indigenous live; column 3 and 4), and a 20% increase or decrease in the stock (column 5 and 6), assuming similar catch rates as status quo (for the commercial non-indigenous live segment). The environmental resource use indicators are: a) GWP, b) Eutrophication, c) Cumulative energy demand.

These scenarios for all fisheries are illustrative, and additional quantitative analyses regarding future scenarios can be undertaken for all the fisheries with a completed LCA. This may be an area for further development to explore options that are of interest to particular sectors and stakeholders (**Section 9).**

Future LCA scenarios: Implications for adaptation

- SRL – changes in abundance and distribution are most likely to impact on the catch phase and hence the global warming potential (GWP) indicator. If reducing greenhouse gas emissions becomes important to consumers, the catch phase will need most attention.
- Wild prawns – increases in availability of wild prawns may lower CPUE with some reduction in GWP at the catch phase, but in the longer term, increases in the export phases may increase the environmental footprint as assessed by the LCA indicators.
- CTS – long term increases in efficiency may occur as a result of fleet and logistic movements south, but an increased environmental footprint is expected in the short term in response to changing fish distributions.
- TRL - a decrease in the environmental footprint is expected from a change in the pathway to the export market (increased efficiency in transport), approximately equivalent to a total reduction is catch (and footprint) of 20%.

7.4 What is a climate-adapted supply chain?

The goal of this project was to consider the impact of climate change across a range of supply chains, and to consider improvements that could lead to a climate-adapted supply chain. Suggesting improvements from a whole-of- supply chain context is difficult at the sectoral level, compared to the individual business-level (**Box 5**). Agreement on what constitutes an “improvement” may depend on the position in the supply chain. For example, reduced costs of purchase may be desired by the end-consumer, but a lower ex-vessel price for fish may not be considered as an improvement by the fisher. In considering adaptation options in this project we have taken the view that improvements that result in more stable supply chains will benefit both fishers and consumers, and be more robust to both climate-related and other forms of disruption.

A robust supply chain will allow growth opportunities when they appear, and if there is disruption to one or more of the critical elements (**Section 7.2.5**) this will not lead to failure in the supply chain, as witnessed for some of the case studies (e.g. closure of the Hong Kong market for SRL, or cessation of harvest on the east coast of Tasmania over Christmas 2012 due to algal blooms[8]).

[8] http://www.abc.net.au/news/2013-02-22/algal-bloom-resurfaces/4534972

Box 5. Best practice supply chains – the business perspective

From a single business perspective, an ideally managed supply chain is one that is managed along the whole length (Storey et al, 2006). In supply chain analysis from a business perspective, four questions are typically relevant to identifying improvements:

1. Who is managing the supply chain in practice (individuals or groups)?
2. What type of supply chain activities are they managing?
3. What are the enablers/inhibitors to this process?
4. What external factors were driving the strategic imperative of supply chain management?

An ideally managed supply chain should have the following 11 characteristics (Storey et al. 2006):

1. Seamless flow from initial source(s) to final customer
2. Demand-led supply chain
3. Shared information across the whole chain
4. Collaboration and partnership across the chain
5. IT enabled
6. All products direct to shelf
7. Batch/ pack size configured to rate of sale
8. Customer responsive
9. Agile and lean
10. Mass customisation
11. Market segmentation

Not all of these are appropriate for fishery supply chains, with

With regard to fishery and aquaculture sectors, we consider that the following characteristics of best practise supply chains are relevant (adapted from Storey et al. (2006), see **Box 5**) and should be a focus for adaptation efforts.

1. Seamless flow from initial source(s) to final customer – identify any critical elements in the supply chain and seek to improve the pathways (e.g. create additional pathways or nodes).
2. Demand-led supply chain – only produce what is needed (thus need to grow the customer demand for the product in order to grow the industry)
3. Shared information across the whole chain – from the producer to the customer and back the other way
4. Collaboration and partnership across the chain – mutual gains and added value for all
5. Batch/pack size configured to the rate of sale – feed into demand-led supply chain
6. Customer responsiveness – what the customers want, value added products
7. Agile and lean – no wastage, can respond quickly to changing customer demands. LCA can be used to identify points of wastage
8. Market segmentation – look to deliver products into different markets (will improve supply chain robustness.

What is an improved fisheries supply chain?

An improved supply chain, from a climate change perspective, can be defined as one made up of organisations that, together, perform markedly better at:

- Reducing waste and efficiently managing resources, thus is leaner from both a cost and an emissions perspective
- Responding to the uncertainties of the environment, thus is more agile and resilient, enabling adaptation
- Responding to the opportunities presented by its changing environment by meeting internal (business strategy) and external (market and stakeholder) needs, thus becoming more competitive and profitable

- Increasing capability, through improved learning and development of staff and continuous improvement of processes and strategies, thus enabling sustainable competitive advantage.

At present, research into climate adaptation in supply chains is limited, and performance measures for successful climate adaptation in supply chains are not available.

8 Benefits and adoption

The beneficiaries of this research are the fishery and aquaculture industries and their relevant management and policy agencies. The benefits of this research to these groups are yet to be realised, as the results have only been generated in recent months. Greater dissemination of the results to the managers and fishers in each case study is now needed. Papers have been prepared for submission, which will be of interest to research community, but to see adoption by industry and management, a different strategy is needed. We have prepared a set of industry-specific fact sheets drawing from all the methods in this project, and have been distributing these at conferences (e.g. Seafood Directions, 2013).

We have met formally with industry groups as part of this project (Table 14), and follow-up is planned with these groups in particular, and with other fisheries (e.g. abalone).

Table 14 Face to face meetings with fishery groups to describe the project and gather initial information to support analyses.

SECTOR	MEETING NAME	MEETING DATES
CTS	Sydney Fish Market	15-16 August 2012
SRL	SEAFAQ	22 August 2012
Wild prawn	Northern Prawn RAG	13-14 September 2012
SRL	Rock Lobster Industry	30 October 2012

This project has an expert group for guidance, with high level managers and policy makers from each state represented. We have provided them with updates through the course of project, and with one final update while the final report was being prepared. Overall, the project has proven more difficult with respect to generating specific adaptation options (we focused on general lessons), and use of these experts did not occur as planned when the project was initiated. Instead, we have prepared fact sheets for communicating general lessons to the individual industries that we considered in this project.

If the project results are considered useful, they should result in efforts by managers and policy makers to assist in creating more robust supply chains. This awareness will be enhanced by the descriptions of product flow, as represented in the supply chain diagrams, identification of the critical elements in the supply chains, and the economic analyses that identified market interactions that may offer growth opportunities.

In some cases, the action for improvement cannot be initiated by the industry or the direct managers, but must be taken at higher levels in government. In such cases, the benefit of this project is to show how these actions would advantage or disadvantage the seafood sector.

9 Further development

There are a number of subsequent steps that could be taken to extend and improve the work presented here, including (i) extending the suite of analyses to other fishery and aquaculture sectors, (ii) developing more detailed quantitative LCA-based scenarios for the current set of fisheries, (iii) development of additional supply chain performance indicators, and (iv) formally integrating the analyses. We outline each of these suggestions in the following paragraphs.

1 Extend the analyses to other fisheries and aquaculture sectors. This project has provided supply chains for seven example fishery and aquaculture industries in Australia, complementing a previous project (Ruello and Associates, 2008) which developed supply chains for several other wild fishery sectors, including the ETBF and SESSF. At present, research into climate adaptation in supply chains is very limited, and performance measures for successful climate adaptation in supply chains are not available. Our supply chain indicators can be compared to a wider set of fisheries and used to develop a clear picture of what a "better" supply chain might look like. Overall, this would more clearly identify the vulnerable export sectors at a national scale, and focus policy on the market support end. Such "whole of industry" vulnerability assessments have been completed at the biological or production end of the supply chain, but not across the chain. Comparison between fisheries and agricultural supply chains, where climate has also been an issue, could also be instructive. For example, lessons regarding development of value adding options as a growth opportunity (seafood largely the same product when purchased, and this was historically the case with livestock products) could be useful.

2 Undertake additional LCA quantitative analyses regarding future scenarios. This extension can be undertaken for all the fisheries with a completed LCA. Just as ecosystem models (e.g. Ecopath (Griffiths et al. 2010; Goldsworthy et al. 2013; Watson et al. 2012), Atlantis) become valuable and ongoing scientific resources once developed for a fishery area, so too should be the LCA. Additional quantitative analyses based on the set of LCAs may be an area for further development to explore in detail options that are of interest to particular sectors. These may include evaluation of the impacts of extreme events on supply chains (e.g. disease outbreaks, abalone and herpes virus, SRO and QX; Tasmania gastro poisoning). Such examination would best be carried out as part of workshops with industry groups, and funding for such an option would largely consist of workshop logistical costs.

3 Development of additional supply chain performance indicators. The LCA resource use indicators (e.g. global warming potential) and the supply chain index stability metrics developed here allow performance of each supply chain to be measured. However, we have not assessed these indicators relative to desirable standards or objectives agreed for each fishery (e.g. Pascoe et al. 2009; Dichmont et al. 2010). In discussion with stakeholders, an agreed set of objectives for the supply chain in question could be developed, and then the adaptation options evaluated relative to these objectives and the indicator metrics. Testing and extension with managers and supply chain stakeholders would be critical.

4 Fully integrated analyses. While claims of "let's link all the parts" are often made, we suggest that holistically examining the impacts of adaptation (or other decisions) on the critical metrics, economic results and LCA results could identify a solution space that is improved across the board. Our results have shown that not all changes will have the expected outcome (e.g. a reduction in supply may not lead to an increase in price), thus formal linking of the physical description of the supply chains with the economic (market) -LCA-critical metric (supply chain indicators) to consider the tradeoffs explicitly could be achieved. This should then be applied to different fisheries on an Australia-wide basis (as was fisheries input output analysis: Norman et al. 2011), and could be extended to the value chain model for the sector (e.g. Nath et al. 2011). Integrated software tools have been effective in illustrating where improvement in whole-of-system performance could be achieved (Bustamante et al. 2011; FRDC 2005/050), and help to explore and evaluate different scenarios to a wide suite of stakeholders.

More detailed information is still to be generated before adaptation options along supply chains might be initiated, and the following additional elements deserve future attention.

5 Review of legacy management arrangements: While not a formal focus in this project, industry profitability in the catching phase can be impacted by inefficiencies or legacy arrangements in management. For example, with changing species distributions, and the impact on catchability, input (e.g. effort restrictions) controls may become less effective than output (e.g. catch quota) controls. Thus, resolving the balance between use of input and output controls, and exploring the negative side effects of both (e.g. Emery et al 2014) is an important future endeavour. As species change distribution, single species allocations or fishery permits may also be limiting to fisher profitability, and management review of entitlement arrangements might also be needed. The FRDC project 2011/039 is considering these issues for four case studies in south-east Australia (southern rock lobster, abalone, snapper and blue grenadier), and concrete recommendations may emerge as a result.

6 True cost of collaboration in the export market: The market-based economic analyses presented here showed that international markets see some Australian products as "equivalent" – prices are not independent for the different rock lobster species. We suggested that greater coordination across the harvesting states would be an advantage, but acknowledge that no formal cost-benefit analysis of this formal coordination was conducted. A future research project could examine with the industry and states, how collaboration in the export market could be achieved, and the economic value realised by such an arrangement, including the advantage of a single stock management arrangement (vs state-based management).

7 Constraints to adaptation: The range of adaptation options proposed by stakeholders in the interviews represents a sub-set of what may be possible. More detailed exploration of each fishery situation is required, as shown in the approach taken by FRDC 2011/039, in which extended consultation for a smaller set of fisheries revealed a more detailed view of the practical, achievable and efficient adaptation options. In particular, the likelihood of proposed adaptation options being achievable given other social and economic constraints was not assessed in detail in this project. Future work, in partnership with industry experts at each stage of seafood supply chains, should consider the trade-offs in implementing each of the potential adaptation options in these cases studies and other seafood sectors.

10 Planned outcomes

The overall premise to this project is that adaptation by Australian fisheries and aquaculture sectors to climate change will be enhanced by increased awareness of markets and opportunities along the supply chain.

The overall planned outcome was development of an approach to generate realistic adaptation management and policy options to enhance "growth and opportunities" along the supply chain. The specific project outcomes as listed in the original proposal were to (i) identify inefficiencies and potential points for enhancing profitability (ii) identification of strengths and weaknesses in the value chain, and together with the LCA, development of adaptation options, and (iii) development of realistic adaptation management and policy options to enhance cost-effectiveness along the supply chain.

The project outputs have contributed to the planned outcomes as follows (Figure 25):

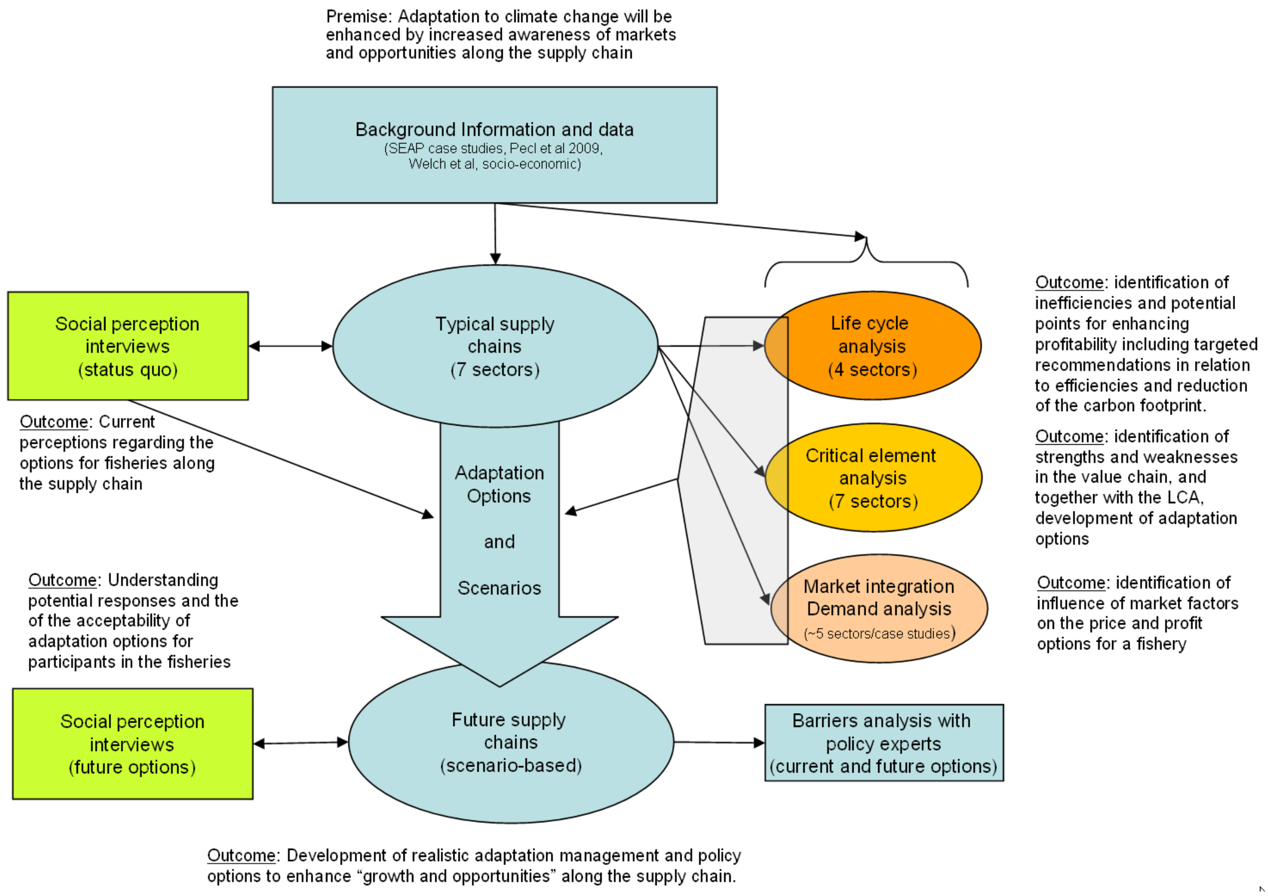


Figure 25 Project linkages and outcomes from each of the methods used to achieve the project objectives.

Current perceptions regarding the options for fisheries along the supply chain were determined, and used to guide development of adaptation options, based on the social perception studies (status quo interviews). Inefficiencies and potential points for enhancing profitability including targeted recommendations in relation to efficiencies and reduction of the carbon footprint were identified using life cycle assessment. Strengths and weaknesses in the chain were identified using critical element analysis and together with the LCA, informed the development of adaptation options. Economic analyses underpinned identification of influence of market factors on the price and profit options for selected sectors. Final interviews evaluated the potential responses and the acceptability of adaptation options for participants in the case studies.

11 Conclusion

The project has met the objectives as described below. Fishery descriptions of seven case studies were completed (**Objective 1**), spanning wild fisheries and aquaculture, a range of taxa, and geographic regions**.** Supply chains for these case studies were generated, and enhanced with estimates of flow of product along different pathways **(Objective 2).** These supply chains were used to support a number of related analyses including life cycle assessment which can underpin improvement in the use of resources along the supply chain. Such improvements may be increasingly important to consumers with increased climate awareness (e.g. carbon miles) and producers (e.g. carbon tax). Interviews with stakeholders generated insight into current awareness of important supply chain issues, while economic analyses showed where links between seafood sectors may restrict the range of adaptation options. New methods were developed to assess the stability of supply chains and identify critical elements. Future scenarios and potential adaptation options were also identified (**Objective 3 and 4**). However, full development of strategies to overcome the barriers and take advantage of the opportunities (**Objective 4**) was not completed as initially proposed. The specificity required for adaptation options required a small set of "general" options to be considered in the project (**Section 6.3.1 and Section 7.3.1)**. Thus, future development of options to overcome barriers should be undertaken in partnership with industry and managers, using the tools developed here, and focusing on an agreed set of options and after defining "supply-chain" related objectives for each fishery.

There is a growing awareness in many climate-exposed primary industries or businesses of the vulnerabilities of supply chains to risks and potential costs associated with the physical and regulatory impacts related to global climate change. However, in the Australian fisheries and aquaculture sectors, our interviewees (**Section 7.2.2)** were focused on the capture phase with only marketing, product description and public perception being a concern at different stages along the supply chain. The pre-occupation of interviewees with the capture phase of the supply chain mirrors the focus of scientific research and literature as well as mainstream media in this area and demonstrates why a broader consideration of the supply chain is needed. In this case, the focus on production-related impacts of climate change might be related to observations of climate-related change identified in many of these regions (e.g. Lough and Hobday 2011; Last et al. 2011; Johnson et al. 2011) which can be linked to the capture phase of fisheries. Impacts further along the supply chain may be considered as "indirect", and may be seen as less certain. This uncertainty presents a dilemma for effective adaptation, as the fishery sectors considered here may fail to identify the need to plan for or, act upon, climate risks at different points along the chain, until flow-on effects become clearer.

Furthermore, while most issues related to the production stage of the supply chain, other opportunities may be unrealized. Additionally, it is important to note that participants in the industries generally felt there was a lot of potential to be constructive in terms of possible adaptation options or improvements in their industry. For example, many participants mentioned improving fuel efficiency, conducting breeding programs, altering the structure of the industry, simplifying regulations and improving public awareness as areas where gains could be made. Many stakeholders (30% in initial interviews) suggested that significant advances could be made by monitoring or modeling key impacts of climate change, indicating a requirement for further scientific information and a degree of trust in science.

Holistic adaptation planning along the supply chain, underpinned by targeted information for the non-harvest elements, is needed. This planning may reduce risk as adaptation options higher up the chain often have long lead times, therefore a delay with regard to adaptation planning may limit future options. A number of potential policy improvements were discussed: working towards better definitions, weightings and/or prioritisation of the objectives for individual fisheries and the sector as a whole; a review of policies with the aim of moving towards a simplification and modernization of regulations to avoid current conflicts and confusions; and more support for recruitment of skilled workers, training and accreditation.

There are also a number of external drivers that need to be managed alongside adaptation options. In Australia, seafood supply chains are influenced by a reliance on imported product to supply domestic requirements and a focus on export for the most valuable products. Therefore the value of the Australian dollar, import/export regulations, trade relations and transport options are all factors impacting decisions and flexibility to change.

Overall, taking a supply chain perspective for the fisheries examined here showed that industry participants are aware of opportunities and barriers across most of the chain, especially at the production end of the chain. Whilst the production end of the chain received most attention, adaptation planning is unlikely to be successful unless all links in the supply chain are considered, particularly where market analyses showed that products were considered as substitutes. In all industries there is a broad range of participant perspectives on how climate change will impact fisheries and a need for more understanding of particular impacts, while at the same time a need to build in flexibility and resilience across the chain. A clear need is to improve collaboration along the chains in each industry through more communication and transparent interactions as well as improved marketing – as they are critical to supporting future adaptation and ongoing supply of seafood.

Appendix A Intellectual property

There are no special intellectual property arrangements. Some contributions to this project were drawn from material that will contribute to PhD theses for Anna Farmery and Peggy Schrobback, and they retain the IP for these elements.

Appendix B Staff engaged on the project

Principal investigator

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Project Expert Group

Brayford, Heather	WA Fisheries
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Fava, Shane	AFMA
Goulstone, Andrew	NSW fisheries
Jones, Annabel	AFMA
Roelofs, Anthony	QLD fisheries
Sloan, Sean	SA Fisheries

Appendix C Fisheries description

In this project, we focused on seven fisheries (case studies), and explored the growth opportunities and critical barriers for each. In the following sub-sections, basic information for each case study is provided, including distribution and biology, fishery description, fishery management, status of the fishery, economic value and likely climate-related changes.

- Southern Rock Lobster
- Tropical rock lobster
- Western Rock Lobster
- Sydney Rock Oyster
- Wild Prawns – Banana Prawns (NPF)
- Aquaculture Prawns
- Commonwealth Trawl Sector

C.1 Southern Rock Lobster

C.1.1 DISTRIBUTION AND BIOLOGY

The Southern Rock Lobster (*Jasus edwardsii*) is found from southern New South Wales, around Tasmania and across South Australia to southern Western Australia.

Adult and juvenile southern rock lobsters are found in a variety of rock reef habitats from rock pools to reefs up to 200 metres deep. They live for 20 years. The fertilisation of southern rock lobster eggs occurs from April to July, where they are carried under the tail of the female for three to six months. Eggs hatch into larvae (phyllosoma) between September and October, with an oceanic phase lasting nine to 24 months. Phyllosoma undergo 11 developmental stages before they moult to the last larval stage and swim towards coastal reefs where they settle as a 25 mm lobster and begin the benthic stage of their lifecycle. Southern rock lobsters are active at night, with day time spent in rock crevices. The southern rock lobster matures between seven and ten years. The grow rate of the southern rock lobster varies spatially with the cooler southern regions having slower growing lobsters and the warmer northern regions have faster growth (Pecl et al. 2011a).

C.1.2 THE FISHERY

The southern rock lobster is fished in Tasmania, Victoria and South Australia and it is one of the most valuable wild fisheries in south-east Australia. In Tasmanian the fishery is managed as a single zone, although the state is divided up into eight stock assessment areas for more detailed regional assessment of the stock (**Figure 26**). In Victoria the fishery is divided into eastern and western zones (**Figure 27**). In South Australia the fishery is managed as two zones; a northern zone and a southern zone (**Figure 28**). Each zone is further divided up into fishing areas for statistical analyses.

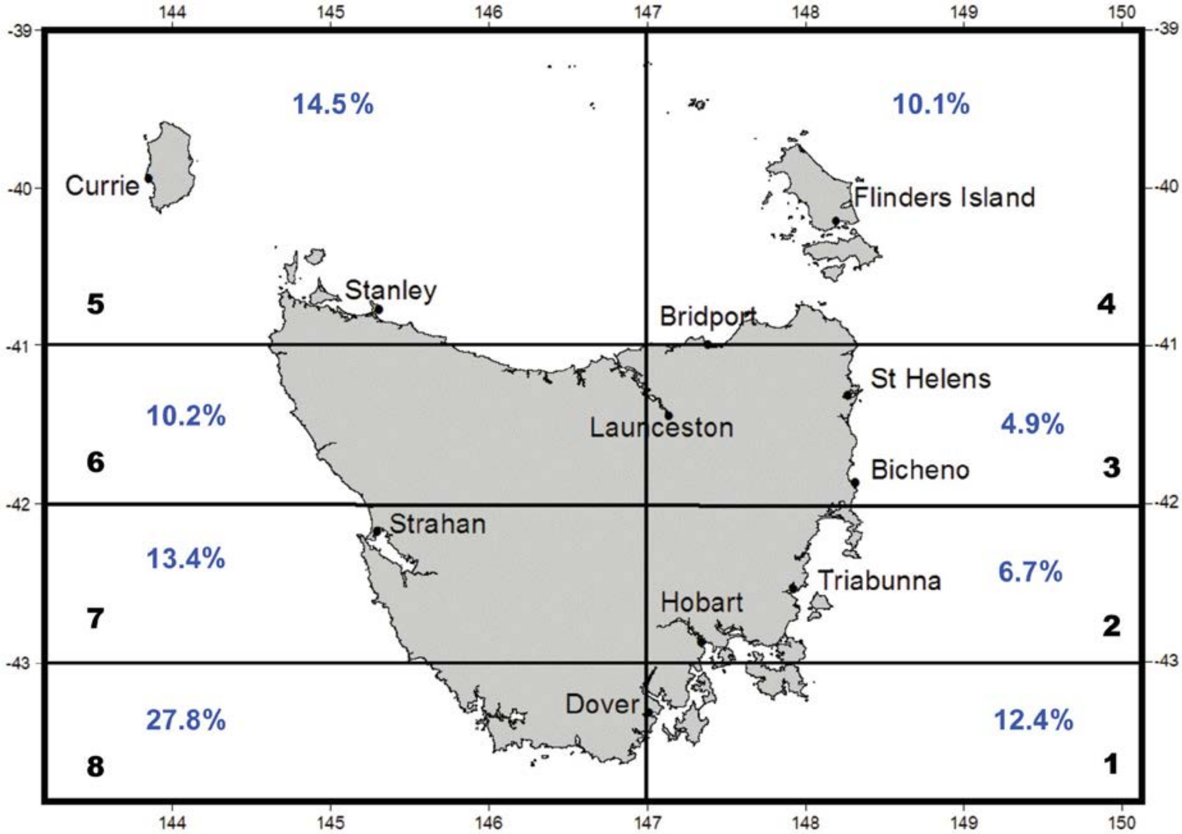

Figure 26 Spatial scale of the eight Tasmanian rock lobster fishery assessment areas. These assessment areas are used as the basis for predicting climate change impacts at 2030 and 2070 in later sections. The figures in blue indicate the percentage of total allowable commercial catch (TACC) taken from each area in the 2006 to 2007 season. Major ports for the commercial rock lobster fishery in Tasmania are also indicated (Pecl et al. 2009).

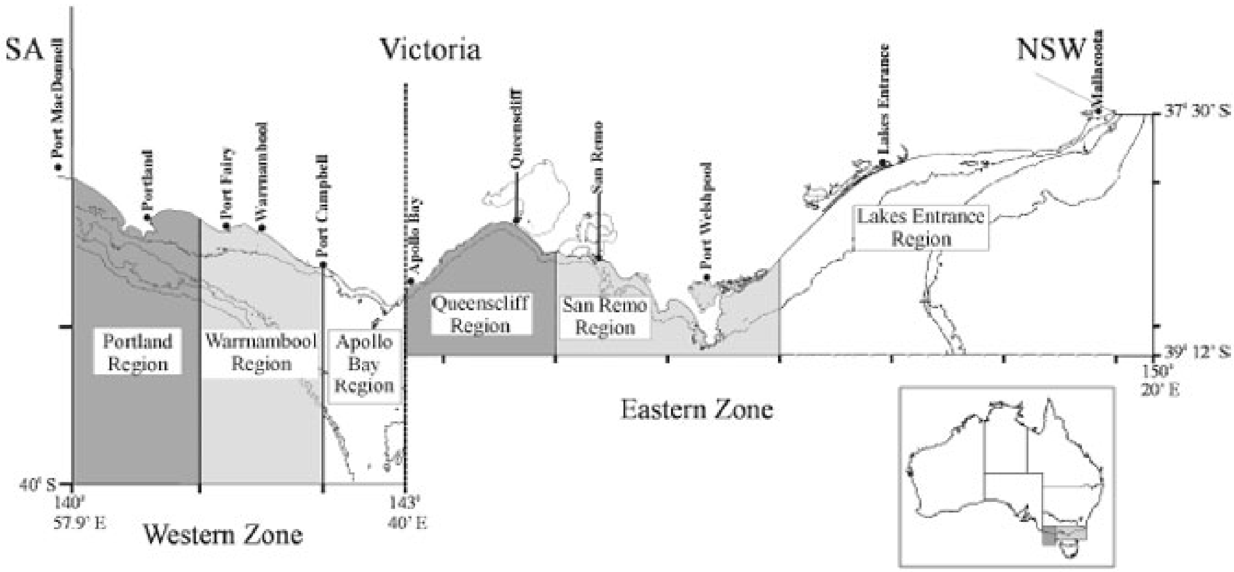

Figure 27 Victorian rock lobster fishery management zone and assessment regions (Department of Primary Industries 2009a).

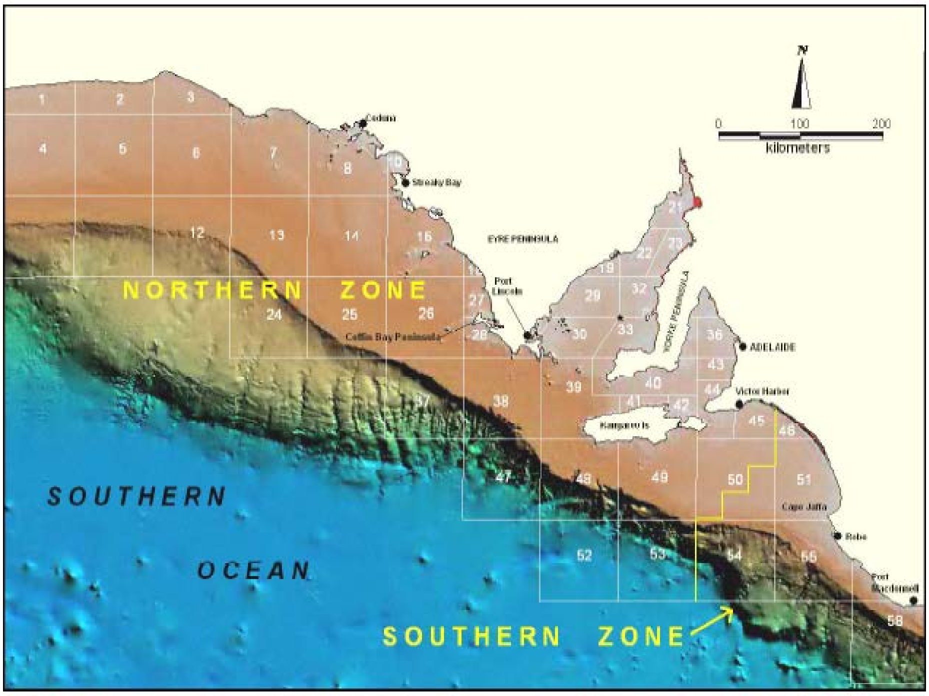

Figure 28 The southern and northern zones of the South Australian rock lobster fishery, the numbered boxes are marine fishing areas used as data collection blocks (Primary Industries and Resources South Australia 2007a).

The southern rock lobster is caught commercially by using baited pots. Once brought onto the fishing vessel they held in either a wet well or a tank with a pump to keep sea water circulating until they are landed. Recreationally southern rock lobsters are caught by diving, baited pots and rings. There are gear and bag limits applied in each state.

In South Australia a number of gear restrictions are in place. The only method permitted for targeting southern rock lobster is a rock lobster pot with specific design specifications. Each commercial licence holder is permitted to use three 'control' pots without escape gaps fitted, for the purposes of monitoring pre-recruit abundance in the fishery through the on-board voluntary catch sampling program. A maximum of 3,950 pots may be registered in the fishery. The maximum number of pots that may be registered on an individual licence is 100 pots. The minimum number of pots that may be registered on a licence is 20 pots (Primary Industries and Resources South Australia 2007b).

C.1.3 FISHERY MANAGEMENT

Tasmania

The Tasmanian rock lobster fishery has been the backbone of the Tasmanian fishing fleet since its inception in the 1800s. Historically, rock lobster fishers had access to virtually all fishing operations, being the owners of most of the sea going vessels. Fishers would rotate their activity depending on seasonal catch rates and market prices of a range of species. In addition to pots, lobster vessels would also carry longlines, droplines, gillnets and dredges. As each of these fisheries came under government regulation, entitlements were issued and diversification of activities declined as dropline, longline, gillnet specific fisheries developed. However, currently, all giant crab licences and a large portion of scallop licences are held by rock lobster licence holders. The Tasmanian Scalefish Management Plan also gives rock lobster licence holders limited access to a wide range of scalefish species and many also have some level of access to Commonwealth fisheries.

Day-to-day management of the fishery is undertaken by the Department of Primary Industry and Water's Wild Fishery Management Branch. The rock lobster fishery is managed by 'rules' based on a statutory five-year management plan. The rules and management plan can be changed or revised within that period following ministerial approval and a process of consultation and public comment on proposed changes. This consultation includes mandated meetings with industry bodies and advisory committees.

Victoria

In Victoria, the Victorian Rock Lobster Fishery Management Plan specifies the policies and strategies for managing the rock lobster fishery in Victoria for at least five years from declaration. The plan establishes arrangements to manage the commercial and recreational catch at levels that prevent overfishing, allow stocks to rebuild and reduce the risks of lower stock abundance in the future. This management plan has been prepared under the requirements of the *Fisheries Act 1995*. This is the second fishery management plan for the rock lobster fishery. The status of the stock and the existing management arrangements of the commercial and recreational fisheries have been reviewed in consultation with major stakeholders. The plan builds on the previous management arrangements and incorporates additional initiatives arising from the review and a risk assessment process.

South Australia

The current management arrangements for both the Southern Zone Rock Lobster Fishery and Northern Zone Rock Lobster Fishery reflect arrangements that have evolved since the 1960s, as well as some major changes that were introduced in 1992 (for southern zone) and 2003 (northern zone) following a major management review.

The commercial fishery is managed using a complex mix of input and output controls aimed at matching harvesting capacity with resource availability. Commercial access to the Southern Zone Rock Lobster Fishery is limited to 181 commercial licences and commercial access to the Northern Zone Rock Lobster Fishery is limited to 68 commercial licences.

In order to hold pots and quota entitlements/units in the commercial fishery, a person must be the holder of a current commercial licence.

In addition to the licence buy-back in 1987 (southern zone) there has been a gradual reduction in licences over time for both the northern and southern zones (an average of 1.3 per year over the last decade, for the northern zone) due to licences being 'split up' where all the pots on a licence are sold separately to other licence holders and the licence is surrendered. Pot reductions have assisted this gradual structural adjustment.

C.1.4 STATUS OF THE FISHERY

Tasmania

The fishery has exhibited a trend of increasing biomass and catch rates over the last decade, although this stock rebuilding has not been evenly distributed around the coast. These spatial patterns are the result of the combined effect of regional patterns in fishing effort and recruitment of lobsters, and also socioeconomic changes that have occurred since the introduction of quota management illustrated, for instance, by the move inshore to catch higher-priced red rock lobster. A number of other social issues arose from the introduction of quota. For example, there is now increased ownership of quota units by non-Tasmanians; the fleet has contracted, the distribution of home ports shifted dramatically; the average number of stakeholders has increased; and the proportion of fishers leasing quota has risen.

Victoria

The status of the southern rock lobster in Victoria is fully exploited. Stock is rebuilding under Individual Transferable Quota management.

Available biomass levels have only increased marginally over the five years since the 2003 plan was declared and remain below 30 per cent of B1951 in both zones. These levels are considered low given the uncertainties the fishery might face in the future from external pressures such as climate change. The low biomass levels result in relatively low catch rates, which in the Western Zone are currently at the lowest level in the history of the fishery. Catch rates in the Eastern Zone have been increasing from very low levels in the mid 1990s and are now approaching that of the Western Zone (**Figure 29**). The falling/low catch rates have had a direct effect on the profitability of the fishery.

The primary strategy of the new management plan will be to significantly rebuild the resource which will improve catch rates and have economic and social benefits by reducing fishing effort and improving economic efficiency.

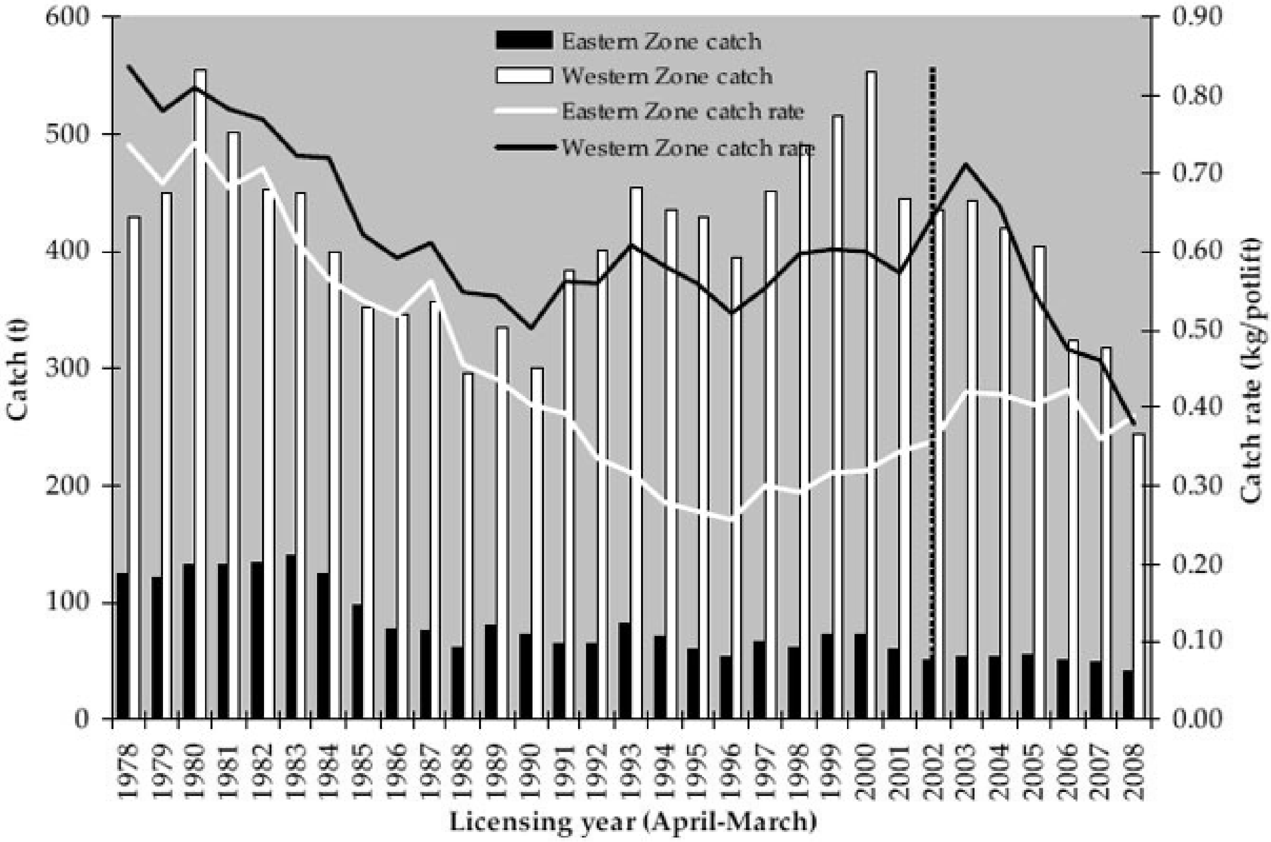

Figure 29 Catch (t) and catch rates (kg/profit) by fishing zone form 1978-1979 to 2008-2009 (April to March). The vertical dotted line marks the introduction of quota management (Department of Primary Industries 2009a).

South Australia

The South Australian Northern Zone is considered over fished. The decline in the total catch is considered to be a direct result of a reduction in the relative biomass of lobster throughout the zone. The most likely cause of the biomass decline is the continued fishing pressure applied to the fishery during an extended period of declining recruitment. Both the catch and effort trends are decreasing (**Figure 30**).

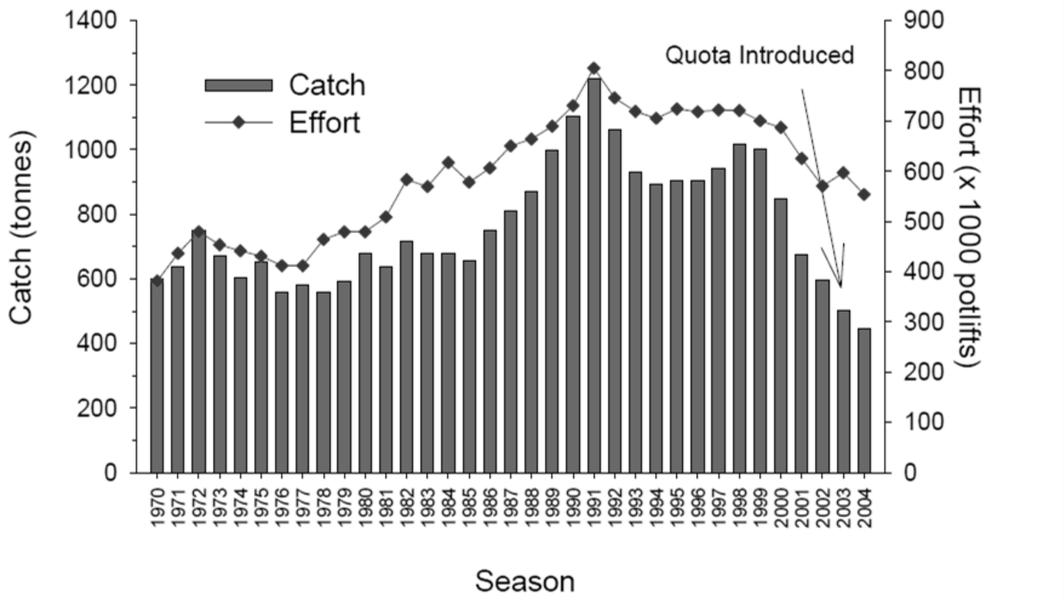

Figure 30 Catch and effort in the northern zone rock lobster fishery for 1970 to 2004 (source: Lianne et al. 2006a).

The South Australian Southern Zone is considered fully fished with harvest levels are at or close to optimum sustainable levels. Current fishing pressure is considered sustainable. Any increase in catch or fishing pressure may lead to over fishing in the long term; both the catch and effort trends are increasing (**Figure 31**).

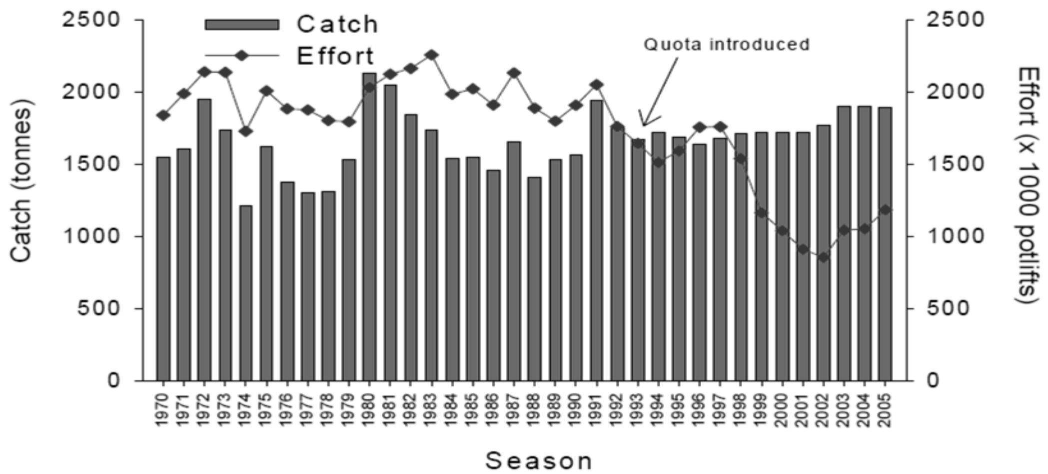

Figure 31 Catch and effort in the southern zone Rock Lobster Fishery for 1970 to 2005(source: Linnane et al. 2006b).

C.1.5 VALUE OF SOUTHERN ROCK LOBSTER

In Tasmania the southern rock lobster fishery in 2010-2011 accounted for 36 percent of the total value of Tasmanian wild catch production ($59.5 million) (Skirtun et al. 2012)

Rock lobster is the second most valuable commercial fishery in Victoria after abalone. The fishery is important to the state's economy and coastal communities, employing about 200 people in the catching sector. The catch in 2008-2009 was 284.8 tonnes valued at about $14.3 million (Department of Primary Industries 2009a).

In South Australia the southern rock lobster fishery is the state's highest value fishing industry ($67 million in 2010-2011). In 2005-2006, catches were 476 tonnes and 1,889 tonnes in the Northern and Southern zones, respectively. More than 95% of the annual catch is exported to a number of destinations, the most significant of which is currently Hong Kong. The total annual export revenue generated by both fisheries is in the order of $110 million per year, while the annual output from both fisheries (direct and flow-on) is currently estimated to be $200 million (Primary Industries and Resources South Australia 2007c).

The export value of all rock lobsters in 2010-2011 was $369.3 million (Skirtun et al. 2012).

C.1.6 PROJECTED ABUNDANCE CHANGE

Habitat loss is one factor that will most likely change the abundance of the southern rock lobster in the future. The sea urchin *Centrostephanus* from NSW has been found in Tasmanian waters. This urchin strips reefs of invertebrate fauna and seaweeds forming barrens which reduce the habitat for SRL. The southward movement of the east Australia current is believed to be the cause of declining recruitment of SRL in eastern Tasmania due to an increase in sea surface temperature (Pecl et al. 2011b)

C.2 Tropical Rock Lobster

C.2.1 DISTRIBUTION AND BIOLOGY

The Tropical Rock Lobster (*Panulirus ornatus)* is found in Australia throughout northern waters from North West Cape in Western Australia to Sydney, New South Wales, but we focus here on the Torres Strait region (**Figure 32).**

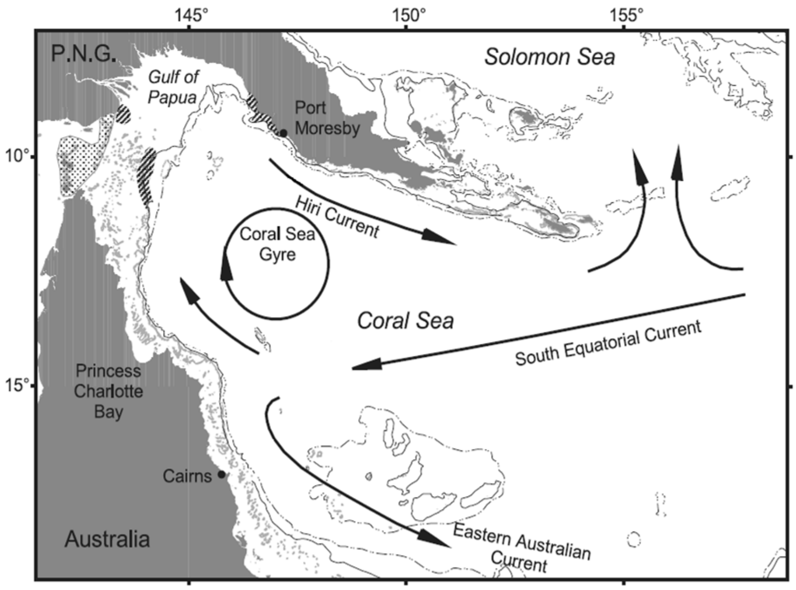

Figure 32 Map of the north-west Coral Sea showing major surface ocean currents, breeding grounds of tropical rock lobster (hatched area), the Torres Strait main fishing grounds around the central and western reefs and islands (dotted). The solid and dashed lines represent the 200 and 1000 metre isobaths (Dennis et al. 2001).

Tropical rock lobsters are found in holes or crevices in shallow reefs where water depths are around 50 metres or the deeper areas between reefs. They generally live for three to five years due to the annual emigration of the two to three year old lobsters to the breeding grounds where females outnumber males in the breeding migrations by 2:1. Large male and one year old lobsters do not migrate. The spawning season in both the eastern Torres Strait and eastern Gulf of Papua is from November to March. Breeding sites include deep water areas on the continental shelf around Yule Island in the Gulf of Papua (**Figure 32**). Adults migrate from reefs in Torres Strait from August to November. Lobsters that migrate to Yule Island generally do not survive after breeding (Pitcher et al. 2005). *P. ornatus* are highly fecund, with mature females brooding clutches of 300 000 to 750 000 eggs and multiple broods may be carried and reared during one spawning season, although the first brood is thought to represent the major spawning within a season. Queensland and Torres Strait *P. ornatus* are considered to be a single genetic stock with Torres Strait and far NE areas being source populations to areas of the GBR further south (Pitcher et al. 2005).

Eggs are fertilised as they exit the female's body and attach to the pleopods, where they are carried for approximately 35 days at 29° C (Pitcher et al. 2005). Larvae hatch as phyllosoma that are carried by wind and tides in the plankton of oceanic waters of the north west Coral Sea and go through as many as 24 morphological stages over approximately six months (Pitcher et al. 2005; Smith et al. 2009). The larvae develop into the peurulus stage which is an active swimming stage that seeks out suitable benthic habitat. The peurulus swims across the continental shelf to settle in coastal areas and as benthic juveniles. Sub-adult lobsters (~95 mm CL) move off-shore during March/April to mid-shelf reefs.

In the NE Australian region the distribution of *P. ornatus* phyllosomas and pueruli in relation to ocean currents support the hypothesis that phyllosomas are transported from the Gulf of Papua breeding grounds by the Hiri boundary current into the Coral Sea Gyre and then by surface onshore currents onto the Queensland coast, Torres Strait and SE Papua New Guinea. There appears to be distinct regions that act as recruitment 'sources' and 'sinks' which is determined by the bifurcation of the South Equatorial Current off the GBR approximately adjacent to Cooktown on the NE Queensland coast. Areas to the north of this bifurcation can be termed both source and sink regions and to the south as a sink region (**Figure 32**) (Dennis et al. 2001; Pitcher et al. 2005). The peak timing of settlement in NE Queensland occurs during winter (June to August) in most years however the seasonality of settlement is highly variable.

Growth of *P. ornatus* has been generalised using the von Bertalanffy growth function and was derived from tag-recapture and aquarium data. Longevity is estimated to be approximately eight years at which *P. ornatus* have a carapace length of approximately 150 mm (Phillips et al. 1992; Skewes et al. 1997). In wild populations larger individuals tend to be males, possible due to higher natural mortality rates on females from the annual breeding migration and egg brooding.

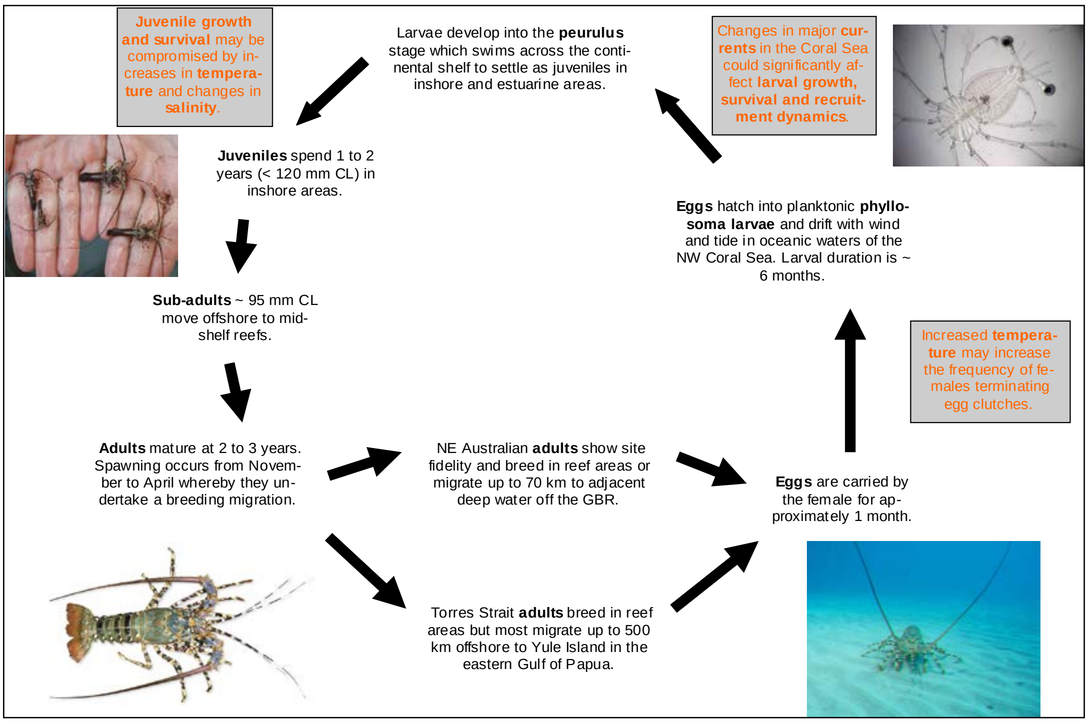

Figure 33 Generalised life cycle of the spiny rock lobster for the north east region of Australia and the stated of potential environmental driver impacts (Welch and Robins unpublished 2013).

C.2.2 THE FISHERY

The Torres Strait Tropical Rock Lobster fishery extends from the tip of Cape York to the northern border of the Torres Strait Protected Zone (**Figure 34**). It is part of the Commonwealth fisheries and is currently the largest commercial fishery in the Torres Strait in terms of catch (763 t in 2010). Two Australian commercial sectors operated within the Torres Strait Protected Zone (TSPZ), the Traditional Inhabitant Boat (TIB) and the Transferable Vessel Holder (TVH) Sector (non-Islanders). Papua New Guinea nationals also fish commercially in the TSPZ. There is also a small recreational fishery.

Sector allocations are based on current agreed shares of the nominal total allowable catch set for the TSPZ by the Tropical Rock Lobster Resource Assessment Group each year. The Torres Strait tropical rock lobster fishery is not subjected to overfishing as the spawning stock biomass is above target with the fishing mortality rate below target.

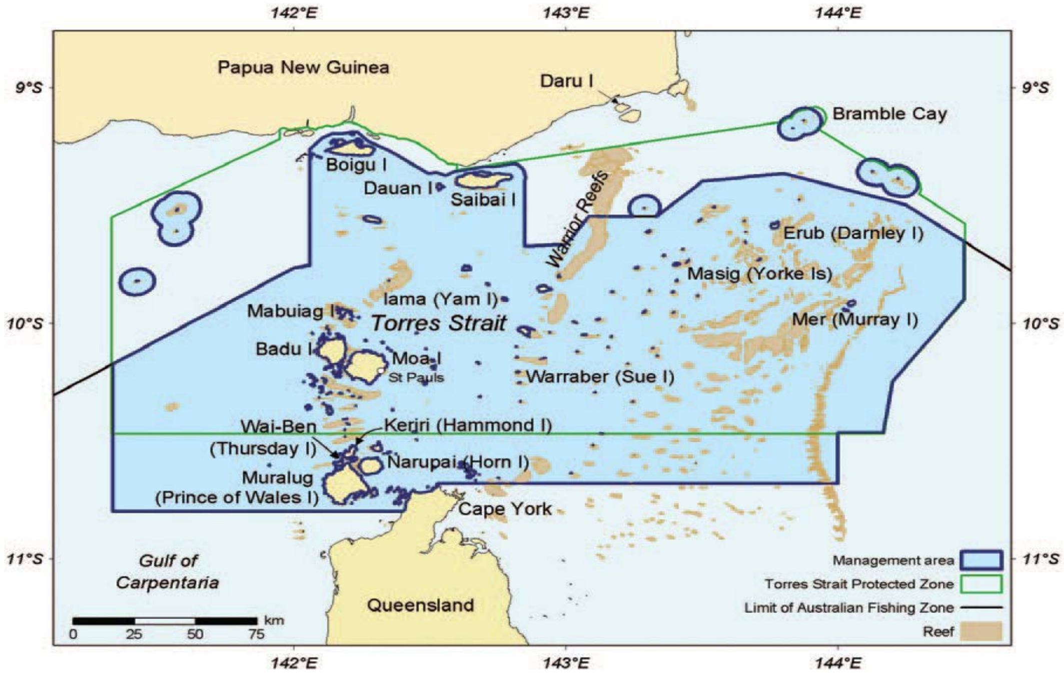

Figure 34 Area of the Torres Strait tropical rock lobster fishery (Woodhams et al. 2011).

Most lobsters are caught during the day by divers using spears or collected by hand or with snares (if sold live). Divers usually work in pairs from dinghies that are about five metres long. Free divers fish down to about four metres, while hookah divers fish at depths of up to 20 metres. Lobsters are caught at night by hand held nets or spears on shallow reef flats. Dive operations consist either of a mother vessel from which a number of smaller (four to six metre) tender vessels operate with divers working from each tender (TVH operators), or of a small four to six metre vessel with divers using solely free diving (TIB).The primary landing ports for the lobsters are Thursday Island, Cairns and Daru Island (Papua New Guinea).

C.2.3 FISHERY MANAGEMENT

Management of the Torres Rock Lobster fishery is under the Torres Strait Fisheries Act 1984 and through policies agreed to under the protected Zone Joint Management Authority. Regulations include restrictions on the number of TVH licenses and how many tenders per primary vessel, however there is no limit on the number of TIB licenses that can be issued. Other regulations include taking of lobster only by hand or hand held implements, a ban on the use of hookah during December and January each year, a minimum tail size of 115 mm or a minimum carapace length of 90 mm to protect pre-recruit and newly recruited lobsters, and bag limits of 3 per person, or 6 per dinghy for recreational fishers and traditional fishing. There is also a ban on commercial fishing during October and November.

C.2.4 STATUS OF THE FISHERY

The fishery catch is managed through a quota system with an annual Total Allowable Catch (TAC) that is shared between Australia and Papua New Guinea. The historical catch from the fishery is variable from year to year and it is thought to be driven by variable recruitment. In 2009 the total catch from the fishery was valued at $AU7.5 M, and was comprised of 228 t (live weight) for the Australian portion (**Figure 35**) and 114 t for the PNG portion. For the 1989 to 2009 time period Papua New Guinea fishers took approximately 31% (range: 19 to 57%)of the total Torres Strait catch. Within the Australian catch, historically the TVH sector has taken the most however in recent years, due to effort controls (regulated and voluntary), most of the catch is taken by the TIB sector and in 2009 they took 59% of the catch (**Table 15**) (AFMA 2010). The most recent assessment of the fishery is that it is not overfished nor is it subject to overfishing.

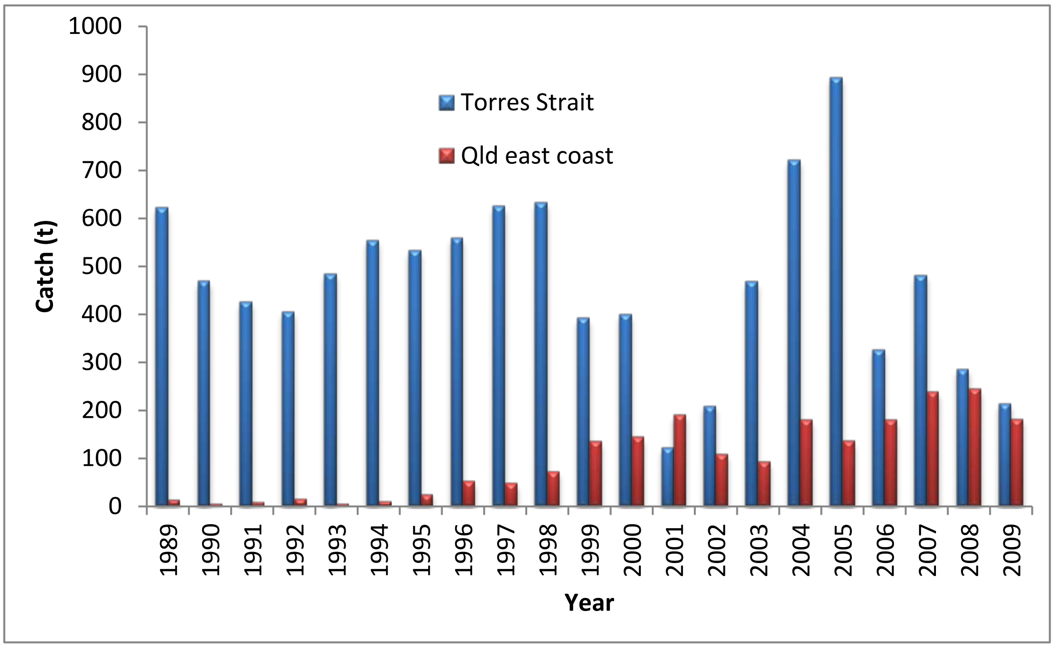

Figure 35 Historical Australian commercial catch for the Torres Strait and commercial catch for the east coast of Australia for the years 1989 to 2009. Catch has been converted to tonnes live weight (Source: AFMA 2010).

Table 15 Catch (whole weight in tonnes) of the non-Indigenous (TVH) sector and the Traditional Inhabitant (TIB) sectors of the Torres Strait Rock Lobster fishery from 2001 to 2009 (Welch and Robins unpublished 2013).

YEAR	TVH	TIB	TOTAL	TIB (%)
2001	70	53	123	43
2002	144	65	209	31
2003	350	118	468	25
2004	465	257	722	36
2005	523	370	893	41
2006	130	196	326	60
2007	257	238	495	48
2008	98	177	274	65
2009	88	126	214	59

Source: AFMA 2010

C.2.5 VALUE OF TORRES STRAIT TROPICAL ROCK LOBSTER

The gross value of production (GVP) has been decreasing every year since 2004 to2005, at an average rate of 18 per cent per year, resulting in a 64 percent decrease since 2004-2005. The decline in GVP has largely been due to decreasing catch. The GVP in 2009-2010 was $6.7 million. Between 2008-2009 and 2009-2010, beach prices fell by 15 percent to $24.70 per kilogram, this is 35 percent higher that 2004-2005 prices. Catch increased by 49 percent between the 2009 and 2010 fishing seasons. This is likely to result in an increase in GVP for 2010-2011. Economic status is uncertain, although net economic returns are likely to be positive. A move to individual transferable quotas may result in improvement in economic efficiency.

C.2.6 PROJECTED ABUNDANCE CHANGE

Temperature and salinity tolerances of *P. ornatus* were investigated by Jones (2009). He found that juvenile growth was significantly affected by temperature with maximum growth in 25 to 31° C water and the optimal temperature being 27° C. Salinity was also found to have a significant effect on juvenile growth and survival with lowest survival but fastest growth at 35 ppt. Sachlikidis et al, (2010) found that *P. ornatus* terminated their egg clutches in temperatures ≥ 32° C. Currents in the NW Coral Sea are extremely important for carrying *P. ornatus* larvae and the determination of areas of settlement (Pitcher et al, 2005). Western rock lobster (*Panulirus cygnus*) are thought to have a decrease in their size at maturity due to rising sea temperatures. The Leeuwin Current (influenced by the Southern Oscillation Cycle) is also thought *P. ornatus* have a broad geographical range and a broad habitat preference. Within the key fishery regions of northern Australia a single genetic stock is present with distinct 'source' and 'sink' regions (Pitcher et al, 2005). Although larval development is approximately six months, under culture situations there is evidence that this period can be as short as four months indicating some plasticity in their early development (Smith et al, 2009). Experimental studies have shown juvenile growth to be maximised between 25 to 31° C water temperatures (Jones (2009), while Sachlikidis et al, (2010) found that *P. ornatus* terminated their egg clutches in temperatures ≥ 32° C.

C.3 Western Rock Lobster

C.3.1 DISTRIBUTION AND BIOLOGY

The western rock lobster (*Panulirus cygnus*) is found along the west coast of Western Australia, between North West Cape and Albany (**Figure 36**), with most found between Geraldton and Perth. The western rock lobster is found in waters ranging from 0 to 120 metres but is commonly found at depths 0 to 90 metres. The species is nocturnal and will shelter during daylight hours in rock crevices and amongst coral. They can live for over 20 years and reach a size of 5kg. They are omnivorous. In their northern range near Kalbarri and the Abrolhos Islands, they mature at a size of 70mm carapace length (CL), while those found in the southern range mature at a length of 90mm CL (Department of Fisheries, Western Australia 2011).

Figure 36 Distribution of the western rock lobster (Department of Fisheries, Western Australia 2011).

The western rock lobsters mate late winter/spring with the male attaching a packet of sperm to the female. The female western rock lobster then spawns in late spring and early summer when they release their eggs and tear open the sperm packet (**Figure 37**). The fertilised eggs become attached to the fine hairs on the "swimmerettes" on the underside of the tail of the female lobster. The eggs hatch after approx four to eight weeks (depending on water temperature) and the tiny larvae are released into the water currents where they spend the next nine to 11 months drifting offshore (from 400 to 1000 km offshore). The larvae (phyllosoma) undergo a series of moults during this time from 2mm on hatching to 35mm long in their final larval stage. The wind and currents carry the phyllosoma back towards the continental shelf. It is here that the phyllosoma change into tiny rock lobsters (pueruli) and swim across the continental shelf to the onshore reefs where they settle. Over the next three to four years the pueruli grow into juvenile rock lobsters. After this time the rock lobsters undergo a synchronised moult and being a migratory phase to the spawning grounds once their shell has hardened. The majority of western rock lobsters head west to deeper water, while a small percentage head north, following the continental shelf (Department of Fisheries, Western Australia 2011).

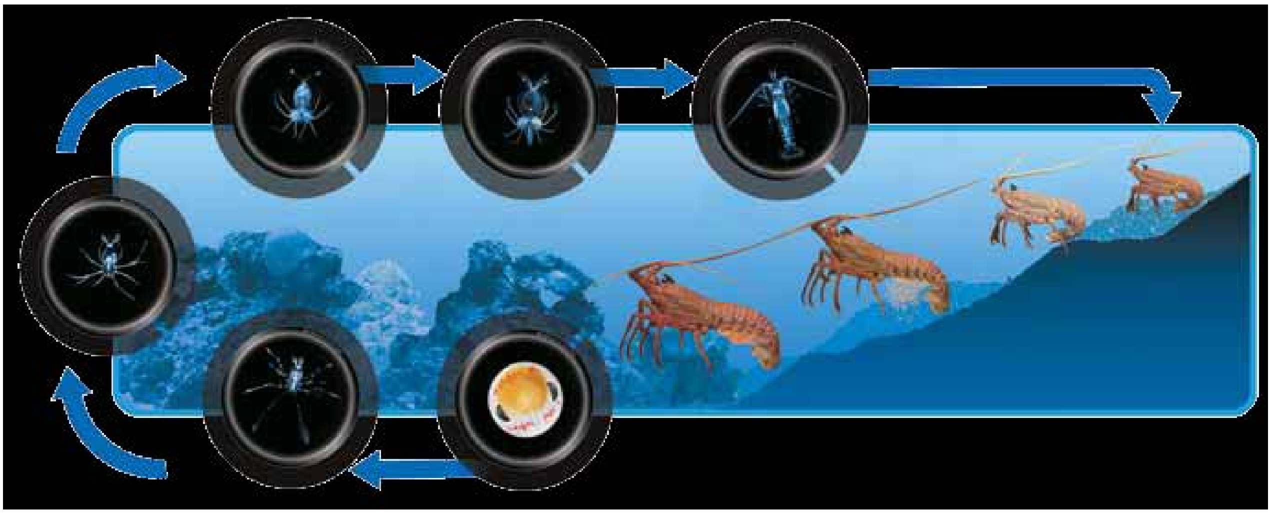

Figure 37 Western Rock Lobster life cycle (Department of Fisheries, Western Australia 2011).

The recruitment of western rock lobster is influences by the water temperature off south-west Australia, the strength of the Leeuwin Current and the strength of the westerly winds. High recruitments have been found to correspond to higher water temperature, stronger Leeuwin current and strong westerly winds in winter (Caputi et al. 2001).

C.3.2 THE FISHERY

The West Coast Rock Lobster (Managed) Fishery targets western rock lobster between Shark Bay and Cape Leeuwin on the Western Australian coastline (**Figure 38**).

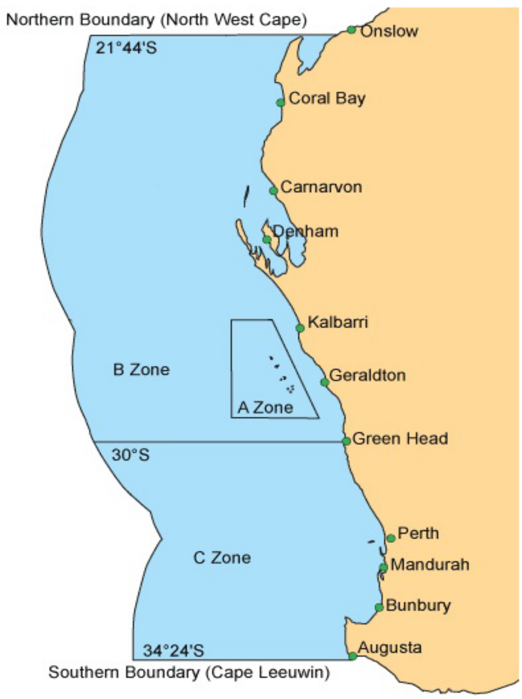

Figure 38 West Coast Rock Lobster (Managed) Fishery (Department of Fisheries, Western Australia 2012).

The fishing season in Zone B and Zone is from 15 November to 30 September each year. In the Abrolhos Islands zone (Zone A) it is from 15 March to 30 September.

It was the first fishery in the world to be certified as ecologically sustainable by the Marine Stewardship Council (MSC) in 2000, the fishery was recertified in December 2006 and again in 2012 (Marine Stewardship Council 2013).

Baited pots are used to fish the lobsters by approximately 280 boats (Department of Fisheries, Western Australia 2011). The pots can be of two designs either a beehive pot made of cane or a batten design made of plastic or wooden slats (de Lestang et al. 2012).

The baited pots are set from boats either near reefs where the lobsters usually live or in regions (usually with a sandy bottom) thought to be on the migration paths. The pots are left overnight to attract the lobsters to the baits. The pots are generally retrieved (pulled) the following morning, though sets of two or more days often occur, particularly when catch rates are low. Captured lobsters of legal size and of appropriate reproductive status (e.g. not setose) are placed into holding tanks and taken to on-shore processing plants, where most are prepared for overseas markets, many as live shipments (de Lestang et al. 2012).

C.3.3 FISHERY MANAGEMENT

The West Coast Rock Lobster fishery comes under the *Fish Resources Management Act 1994*, the *Fish Resources Management Regulations 1995*, *The West Coast Rock Lobster Management Plan 1993*, as well as the West Coast Rock Lobster Managed Fishery Licence, and the Commonwealth Government *Environment Protection and Biodiversity Conservation Act 1999 (Export Exemption).*

In 1963 it was declared limited entry fishery which froze pot and licence numbers. Since 1963 the fishery has undertaken management changes that have been designed to keep stock sustainable (de Lestang et al. 2012).

The West Coast Rock Lobster Fishery operates under a quota system based on entitlement to use pots held by licensed fishers and the relevant share of the total allowable catch set for the various zones, where the fishers are licensed to operate. For each year’s commercial fishing season the total allowable catch across all zones is set annually. The quota can vary from time to time, depending on factors like the success of puerulus settlement. The "Puerulus Settlement Index" is used to predict the stock level up to four years in advance. This enables management settings for the fishery to be adjusted accordingly. The Western Australian State Government through the integrated fisheries management process determines the Total Allowable Catch (TAC) for the fishery. At present the resource it allocated as follows: 95% to commercial sector, 5% to the recreational sector and one tonne to customary fishers.

Commercial western rock lobster fishers are required to complete and submit Catch and Disposal Record (CDR) forms which involves the use of an Interactive Voice Response (IVR) system. The CDR provides the means by which catches of rock lobster are deducted from a managed fishery licensee's quota allocation. The IVR is used to provided information on where the fishing vessel is headed, when it about to fish, when it has fished and where the catch will be landed (Department of Fisheries, Western Australia 2013).

C.3.4 STATUS OF THE FISHERY

The stock status of the western rock lobster is considered acceptable, with the total allowable commercial catch in 2010 being 5500 tonnes (Department of Fisheries, Western Australia 2012).

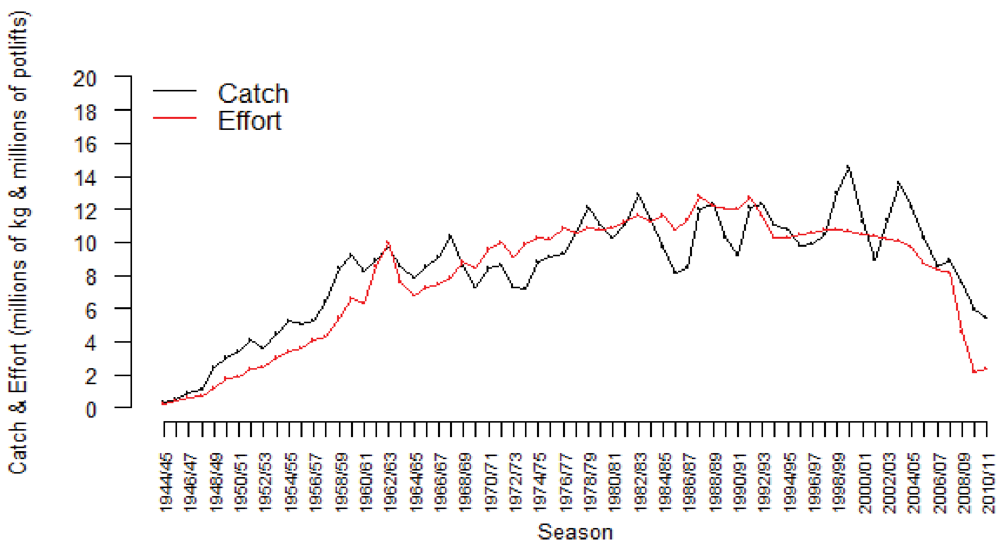

Figure 39 Annual catch and effort for western rock lobster in the West Coast Rock Lobster Managed Fishery (de Lestang et al. 2012).

The West Coast Rock Lobster Managed Fishery took off in the 1940s. By the mid 1950s annual catches were over eight million kilograms. Total allowable catch limits were introduced in 1963, and since the 1980s the annual catch has been approx 11 million kilograms (**Figure 39**). Recent management measures due to low recruitment levels has set the total allowable commercial catch (TACC)at 5500 tonnes for the 2009-2010 season and this TACC was maintained for 2010-2011 using individual catch limits (de Lestang et al. 2012).

C.3.5 VALUE OF WESTERN ROCK LOBSTER

The western rock lobster commercial catch is worth between $200 million and $400 million, which is approximately 20% of the total value of Australian fisheries (de Lestang et al. 2012). In 2010-2011 Western Australia exported $198.2 million of western rock lobster, which is 54 percent of the total Australian rock lobster export value (Skirtun et al. 2012).

C.3.6 PROJECTED ABUNDANCE CHANGE

The recruitment of western rock lobster is influenced by water temperature, the strength of the Leeuwin Current and the strength of westerly winds. Higher recruitment occurs when higher water temperatures and a stronger Leeuwin Current along with stronger westerly winds in winter are present (Feng et al. 2012). A stronger Leeuwin current also increased the settlement of the puerulus along the south of the coast (Caputi et al. 2010b).

With warming water temperatures the size at maturity has been found to decrease along with a decrease in the size of migrating lobsters from shallow to deep water. This also leads to an increase in abundance of undersize and legal size lobsters in the deeper waters, which in turn shifts the catch area to deeper waters. (Caputi et al. 2010b).

C.4 Sydney rock oyster

C.4.1 DISTRIBUTION AND BIOLOGY

Sydney rock oysters (*Saccostrea glomerata*) are endemic to Australia and are found in sheltered bays and estuaries where the adults attach themselves to rocks. They occur naturally from Hervey Bay in Queensland to Wingan Inlet in Victoria. They are cultivated in a number of locations within this region.

The lifecycle of the oyster begins with the spawning of male and female oysters. After two to three weeks the larvae settle and attach themselves to a surface where they continue to grow. Small oysters less than 12 months old are called ‘Spat’. Sydney rock oysters reach approximately 60 grams in three years. They have been known to live for up to ten years. Sydney rock oysters start out as males and later change to females (NSW DPI 2012).

C.4.2 THE FISHERY

In NSW they are farmed along the coast (**Figure 40**).

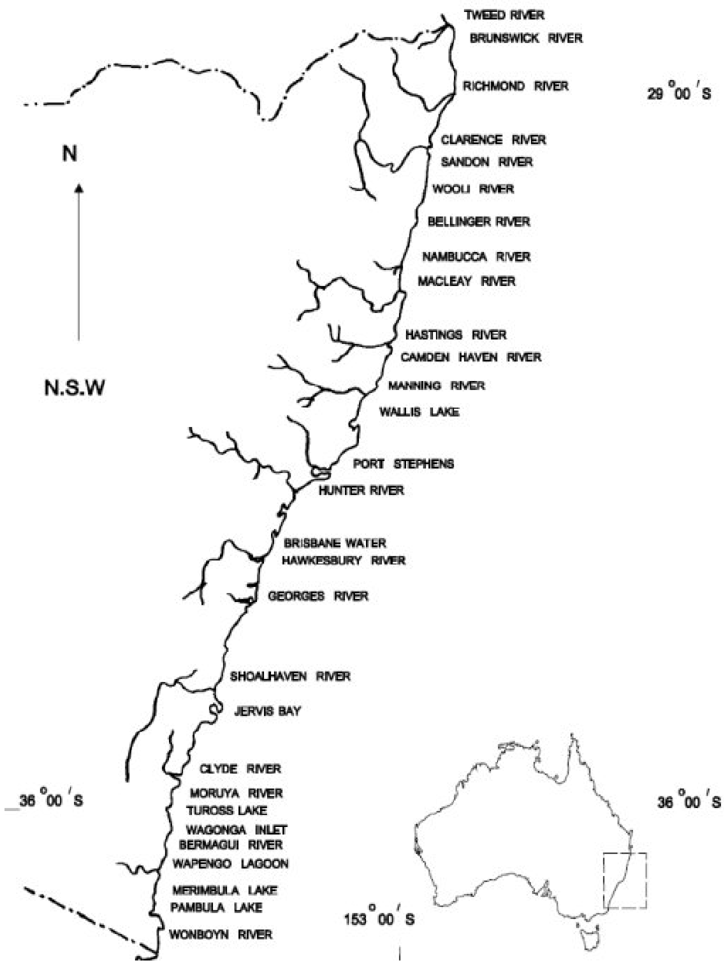

Figure 40 Major oyster producing estuaries in New South Wales (NSW Department of Primary Industries 2012).

There are three different cultivation techniques used in NSW. These are stick culture, rock culture and tray culture. Rock culture is seldom practiced. Stick culture commences with oyster larvae (spat) settling on tarred hardwood sticks 1.8 metres long and 25 mm square, which are placed in areas of estuaries where spatfall is most reliable, typically near river mouths. The sticks are then moved to low spatfall areas to reduce "overcatch" (when already growing oysters have spatfall settle on them) and are grown to maturity on horizontal racks in the inter-tidal zone. The process takes from 3 to 4 years with great care required in the first two years to protect the oysters from excessive heat and predators (bream, octopus and stingray). At maturity, the oysters are removed from the sticks and graded into various sizes prior to marketing. The largest (15 to 25 oysters per kg) are sold as first grade oysters and the next grades (25 to 35 per kg) are sold as "bistro" or "bottle" grade. Oysters too small to meet either of these criteria are usually placed onto trays and returned to the same or other estuaries to develop to a marketable size.

Tray culture commences with an oyster tray, usually one metre wide and from 1.8 to 2.7 metres in length, made from timber and wire or plastic, into which oyster spat is placed from sticks or PVC slats, when the oysters are approximately 3 to 8 mm in diameter. Oysters grown in this method are easier to manage and grow in a more uniform and marketable shape due to the stocking densities in the trays.

Tray culture has also lead to "single seed technology" where the oyster spat from the catching surface is either placed on specially constructed trays or in plastic mesh cylinders or baskets. These trays or baskets provide ideal growing conditions where the oysters do not get clumped together or misshapen, faster growth rates have been reported by oyster farmers. Single seed techniques require substantial capital investment but this is offset by faster growing, better shaped oysters which allow a more precise grading and the oysters generally receive a higher market price.

There is research into the commercial production of "triploid" oysters, which are oysters that grow fast and hold market condition longer, which is aimed at further enhancing the viability of single seed culture.

C.4.3 FISHERY MANAGEMENT

There are approximately 3200 oyster aquaculture leases in NSW, which are administered by NSW Department of Primary Industries.

C.4.4 STATUS OF THE FISHERY

Commercial production occurs in 33 estuaries along the state with Wallis Lake and the Clyde River producing the majority of oysters. The growing areas of the SRO are subjected to a range of environmental stresses such as high rainfall, algal blooms and disease. The occurrence of QX disease in patches from southern Queensland to the Georges River in NSW restricts the tidal areas where oysters can be viably grown to a shortened season. QX disease has historically occurred in the growing regions of southern Queensland and northern NSW. From a study undertaken by the NSWDPI between 2001 and 2004 it was found that the presence of QX disease (*Marteilia sydneyi*) is found all along the NSW coastline (NSW DPI[9]). There is currently a Fishing closure QX disease for the taking of oysters for the purpose of relocating and relaying oyster between estuaries for Category 1, Category 2 and Category 3 Estuaries[10]. This closure of movement of oysters remains in force for five years. The oysters are still considered safe for human consumption.

C.4.5 VALUE OF SYDNEY ROCK OYSTER

Sydney rock oysters are sold by grade, these being in order of decreasing size, Plate Grade, Bistro Grade and Bottle Grade, with Plate Grade fetching the highest prices. In NSW, the Sydney rock oyster produced over $31.5 million dollars or 5.2 million dozen oysters for 2010-2011 (**Table 16**). The Wallis Lake estuary produced over $10.1 million dollars in oyster sales alone (Trenaman 2011).

[9] NSWDPI <http://www.dpi.nsw.gov.au/fisheries/pests-diseases/animal-health/aquaculture/qx-oyster-disease>
[10] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/286416/QX-risk-based-closure-16-9-2011.pdf

Table 16 Sydney rock oyster sales by production method for NSW (Please Note: Due to rounding effect there may be some small variances in bag quantities & $ value).

TYPE OF CULTIVATION	PLATE GRADE			BISTRO GRADE			BOTTLE GRADE			TOTAL		
	Bags	Dozens	Value ($)	Bags	Dozens	Value ($)	Bags	Dozens	Value ($)	Bags	Dozens	Value ($)
Dredge	26	2,611	$22,011	11	1,256	$8,101	8	1,084	$4,900	46	4,951	$35,012
Floating basket	1,172	117,228	$988,232	1,831	201,398	$1,299,017	2,069	268,917	$1,215,505	5072	587,543	$3,502,754
Longline basket	244	2,435	$205,131	269	29,622	$191,062	321	41,691	$188,457	834	95,671	$584,831
Raft/ Pontoon	849	84,939	$716,036	1,122	123,400	$795,930	1,403	182,397	$824,434	3374	390,736	$236,400
Slats	188	18,779	$158,307	292	3,2139	$207,297	83	36,741	$166,069	763	87,659	$531,673
Stick	473	47,250	$398,318	787	86,536	$558,157	1,239	16,1126	$728,290	2499	294,912	$1,684,764
Tray	8,619	861,866	$7,265,530	11,196	1,231,601	$7,943,826	12,987	1,688,295	$7,631,093	32802	3,781,762	$22,840,450
Totals	11,570	157,028	$9,753,746	15,509	1,705,952	$1,103,390	18,310	2,380,254	$10,758,748	45389	5243,234	$31,515,885

Source: Aquaculture Production Report 2010/2011

C.4.6 PROJECTED ABUNDANCE CHANGE

Increasing the quantity of SRO production is limited due to the availability of lease area, quality & quantity of spat, environmental pressure caused by urbanisation (e.g. sewage and agricultural run-off), spatial competition from diploid & triploid Pacific oyster that are increasingly grown in NSW, effects caused by a warming Eastern Australian current effect on spat recruitment, predicated high-rainfall and storm events may adversely affect growth and harvest (Schrobback 2012).

C.5 Wild banana prawns

C.5.1 DISTRIBUTION AND BIOLOGY

This fishery is part of a larger Commonwealth managed fishery in northern Australia, the Northern Prawn Fishery (NPF). It targets a complex of nine commercial species of Penneids prawns (AFMA 2013, NPF at a glance[11]). The banana prawn fishery includes two target species, the White Banana (*Fenneropenaeus merguiensis*) and the Red-legged Banana (*F. indicus*). These two species have wide tropical and sub-tropical distributions, ranging from the Indo-West Pacific: E. and S.E. Africa to S. China, New Guinea and Australia (FAO 2010-2013). In Australia they are found across the north, west and east tropical and sub-tropical shallow coastal and estuarine ecosystems (**Figure 41**). White banana prawns are found from Shark Bay in Western Australia across the northern tropics of Australia to the Tweed River in northern New South Wales on the east coast. Red-legged banana prawns are exclusive to the north tropical coast of Australia. There are found from their western limit at Broome, Western Australia, across the Kimberly and Arnhem Land coasts to the north-west margin of the Gulf of Carpentaria (GoC). They are not found in fishing quantities in the GoC or Torres Strait. Their abundant distribution in northern Australia is limited to the north-west Arnhem Land coast. The only commercially fished populations of red-legged banana prawns are those in the Joseph Bonaparte Gulf and on the western Arnhem Land coast (Melville Island/Coburg Peninsula) (Kenyon et al. 2004).

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[11] http://www.afma.gov.au/managing-our-fisheries/fisheries-a-to-z-index/northern-prawn-fishery/at-a-glance/#.USsCyKUu4dJ

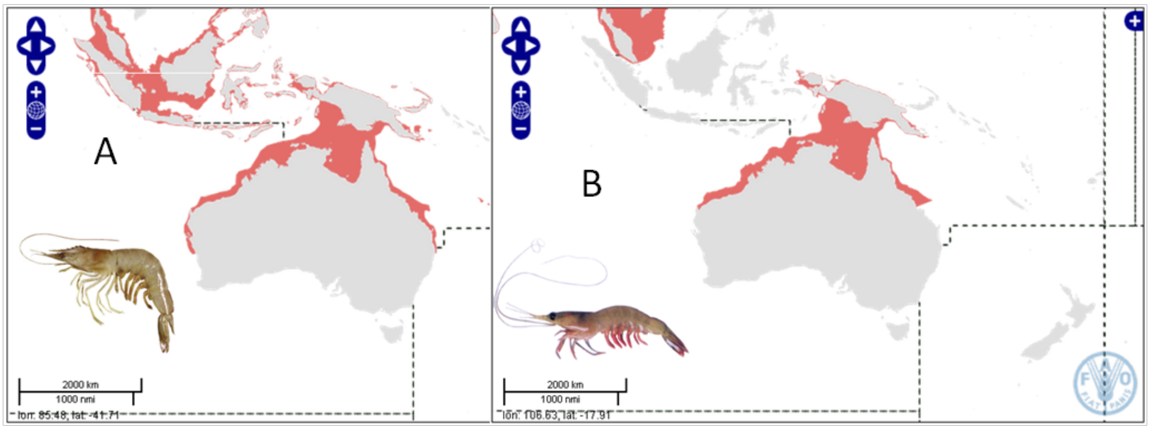


Figure 41 Species distribution in Australia and the region for a) the white banana (*Fenneropenaeus merguiensis*) and b) the Red-legged Banana (*F. indicus)* (FAO 2010-2013).

According to Kenyon et al. (2004), both species use mangrove/mud habitats and, at low tide, are most abundant in small tidal creeks and gutters that drain mangrove forests (**Figure 42**). Small juvenile banana prawns are more abundant in these small tributaries than in the larger creeks and rivers that they flow into, though as they grow they move to larger water bodies. Experiments have shown that juvenile white banana prawns use the whole mangrove forest at high tide, moving into the forest on the flood tide and retreating from it on the ebb tide. They are more abundant in the near-creek regions of the forest and accumulate in remnant water bodies at low tide. Red-legged banana prawns are found in remnant water bodies among mangroves forests and in mangrove-lined creeks, as well. In all probably, they use the mangrove forest habitats in the same way as white banana prawns. Both species of banana prawns probably gain protection from predators within the forest structure at high tide and among highly turbid near-bank waters at low tide. Juvenile white banana prawns grow rapidly in the estuary (about 1.2 mm carapace length (CL) per week). Their emigration from the estuaries is strongly cued by a decline in salinity during flood events and the population offshore is correlated to rainfall (due to flood cued emigration). Juvenile white banana prawns emigrate at 8 to 14 mm CL; prawns emigrating at a smaller size during flood events. They continue to grow as they emigrate offshore to water depths greater than 15 m. Large adults may move inshore at spawning. In the GoC, the populations of white banana prawns are adjacent to the extensive mangrove nursery areas that support them, usually less that 50 km separates the juvenile and adult habitats. In contrast, in Joseph Bonaparte Gulf the mangrove habitats that support the red-legged juveniles are 150-240 km to the south and south east of the distribution of the adult population (in the north-west of the Gulf). In Australia, red-legged banana prawns live in deeper waters (35-90 m) than the common banana prawns (15-45 m). They both are found on muddy substrates. Their depth ranges maybe related to their geographic distribution, as red-legged banana prawns are confined to northern areas with deeper waters adjacent to the coastal nursery habitats. In the GoC, white banana prawns aggregate into dense schools (up to 400 t) in waters 15-25 m depth, while, in Joseph Bonaparte Gulf, redlegged banana prawns aggregate, though not to form the same dense schools as white banana prawns. Although the white banana prawn occurs along the Papua New Guinea coast line and is a major fishery in the adjacent Gulf of Papua, this species does not occur in the Torres Strait prawn fishery. In the GoC, banana prawns spawn over two main periods, September to November and March to May; the smaller September to November spawning contributes to next year's recruits. Thus, the stock of adult spawners must survive significant fishing activity in April/May to contribute to the next year's stock. Banana prawns are highly fecund and females may produce 100 000 – 400 000 eggs. The minimum size at first maturity is about 26–34 mm CL (about 6 months old). They live to 12-18 months. The spawning cycles, fecundity and size at first maturity of red-legged banana prawns are unknown (Kenyon et al. 2004).

As adults, common banana prawns bury; though during the day they emerge more often than tiger prawns. Burying behaviour can be replaced by schooling behavior as a predator avoidance mechanism. The behaviour of red-legged banana prawns has not been studied, though prawns kept in tanks for three months to assess the effect of streamer tags on mortality often buried in the sand substrate of the tanks. The diet of common banana prawns consists of small bivalve molluscs and polychaete worms, while that of red-legged banana prawns is unknown. Adult banana prawns are preyed upon by trevally, sharks, rays and other fish. The predators of red-legged banana prawns are not known, but probably are similar to the common banana prawn (Kenyon et al. 2004).

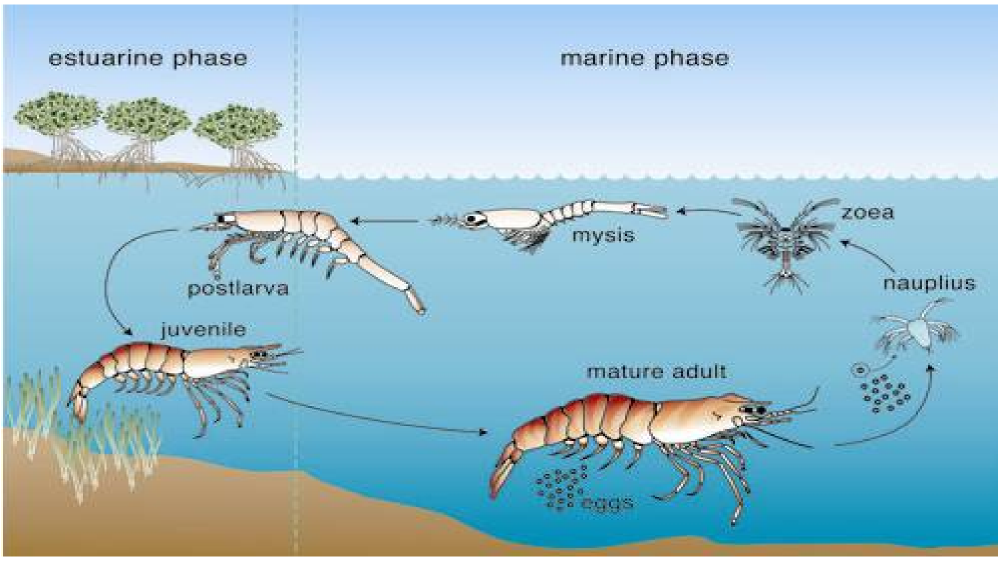


Figure 42 Generalised lifecycle of the penaeid prawn. Some prawns use littoral seagrass habitats as nursery areas, others use mangroves and estuarine and freshwater creeks, while others use bank habitats (Kenyon et al. 2004).

C.5.2 THE FISHERY

The Northern Prawn Fishery (NPF) occupies an area of 771,000 square kilometres off Australia's northern coast. The Fishery extends from the low water mark to the outer edge of the Australian fishing zone along approximately 6,000 kilometres of coastline between Cape York in Queensland and Cape Londonderry in Western Australia (**Figure 43**).

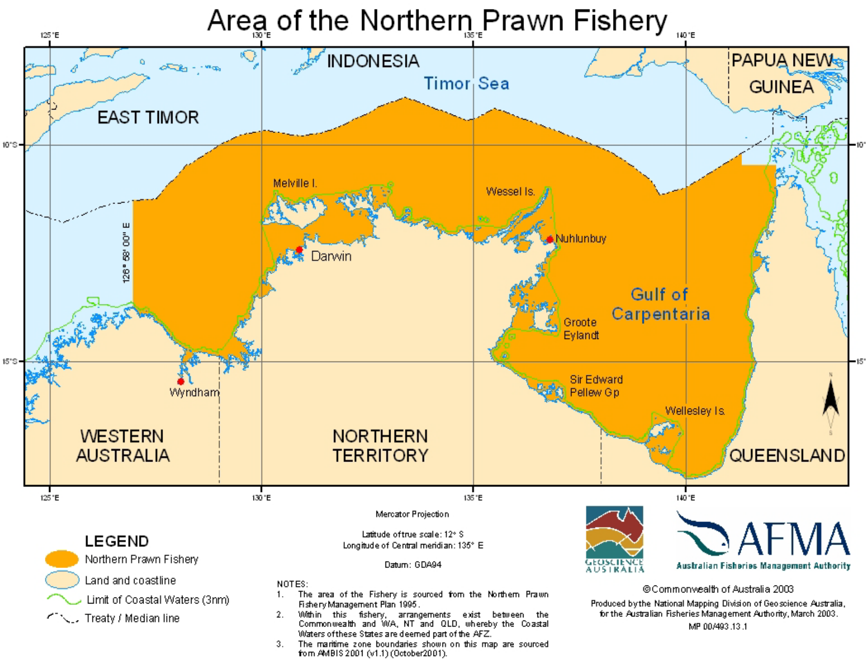


Figure 43 Map of the Northern Prawn Fishery,© Commonwealth of Australia 2005.

The NPF is a multispecies fishery that catches prawns using otter trawl gear. White banana prawn and two species of tiger prawn (brown and grooved) account for around 80 per cent of the landed catch. Important quantities of byproduct species include scampi (*Metanephrops* spp.), bugs (*Thenus* spp.) and commercial scallops (*Amusium* spp.). White banana prawns are mainly caught during the day on the eastern side of the Arnhem Land coast, whereas red-legged banana prawns are mainly caught in the Joseph Bonaparte Gulf (**Figure 44**). White banana prawns form dense aggregations ('boils') that can be located using spotter planes, which then direct the trawlers to the aggregations. The highest catches are taken offshore from mangrove forests, which are the juvenile nursery areas. The bulk of catches come from the southern and western Gulf of Carpentaria and along the Arnhem Land coast. The fishery season for banana prawn is six to 12 weeks in duration, starting around April each year.

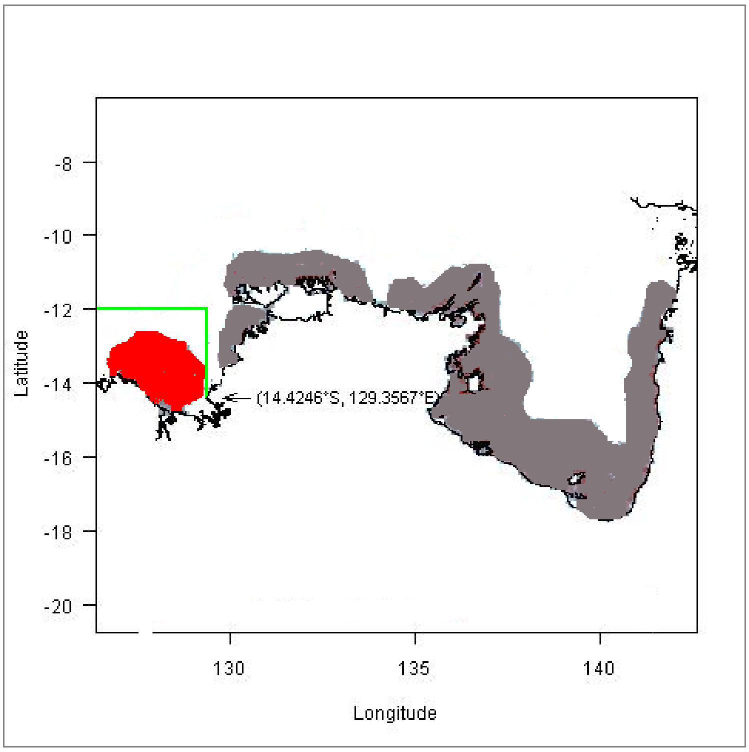


Figure 44 Area of the Northern Prawn Fishery trawling grounds (grey) indicating also the main fishing ground in the Gulf of Joseph Bonaparte for *F. indicus* (red) (Plaganyi et al. 2012).

C.5.3 FISHERY MANAGEMENT

The NPF is managed through a series of input controls, including limited entry to the fishery, gear restrictions, bycatch restrictions and a system of seasonal, spatial and temporal closures. These management restrictions are implemented under the Northern Prawn Fishery Management Plan 1995. To fish in the NPF operators must hold Statutory Fishing Rights. These rights control the level of fishing by placing limits on the numbers of trawlers and the size of gear permitted in the fishery. Effort in the fishery is currently controlled by input restrictions, including gear units. However, the fishery is in the process of moving to output controls, in the form of total allowable catches (TACs) and individual transferable quotas ITQs (AFMA 2012).

There are two distinct components of the NPF harvest strategy, to manage the two components of the fishery (banana prawns and tiger prawns). Both operate within the current management system of input controls (Dichmont et al. 2012). Both components are managed through season length and the monitoring of catch rates. The tiger prawns harvest strategy has been subjected to management strategy evaluation testing to assess its performance against the Commonwealth Fisheries Harvest Strategy Policy (DAFF 2007).

Likely changes to management of a number of stocks through output controls are driving a revision of the NPF harvest strategy (taken from Woodshams et al. 2011).

C.5.4 STATUS OF THE FISHERY

The latest status report for the White Banana prawn, the species that account for most of this fishery, has stated that fishing mortality is thought to have been high for white banana prawns in some past years. However, with the reduction in fleet size, adoption of the harvest strategy and lack of evidence of recruitment overfishing, this stock is classified as not subject to overfishing and not overfished. Red-legged Banana prawns comprise a relatively small percentage of the total prawn catch and are one of the less well-assessed species in the NPF, however recent assessments suggested that the current status of the stock suggests that it is healthy (Plaganyi et al. 2012) (**Figure 45).**

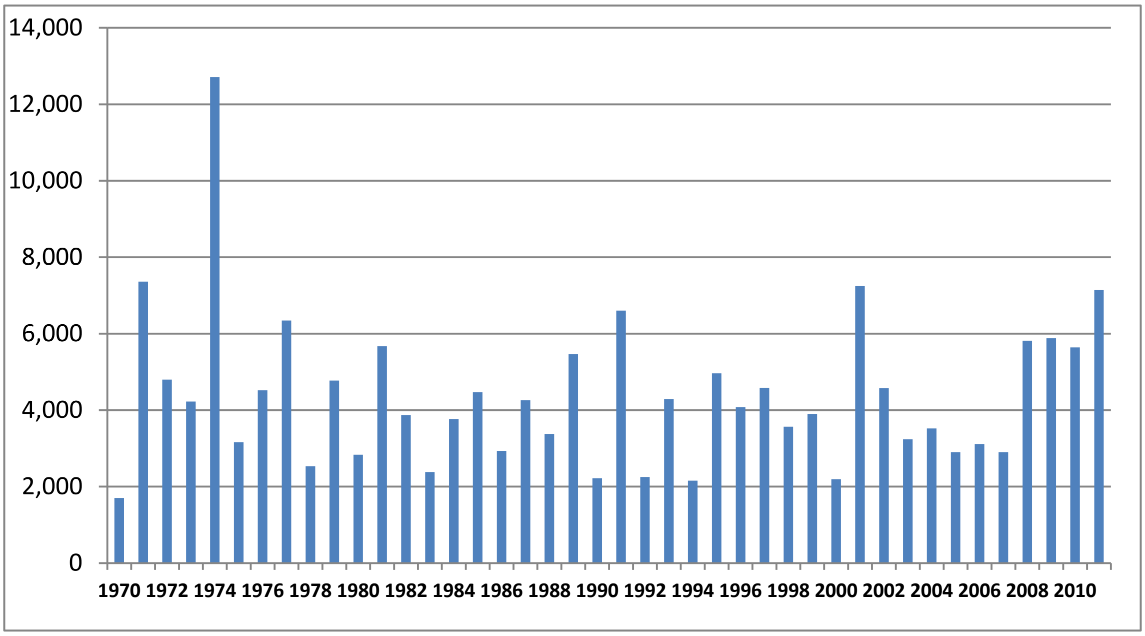


Figure 45 Total historic catch (tonnes) series (1980-2011) for all Banana prawns (from Barwick 2012).

White Banana Prawn

Recruitment of White Banana Prawns in the Northern Prawn Fishery (Commonwealth) is thought to be largely determined by rainfall. As a result, a reliable stock–recruitment relationship has not been established (Roach et al. 2012). No formal stock assessment exists for this stock. However, a model that predicts catch, using rainfall data, is currently being developed by CSIRO.

The harvest strategy for White Banana Prawns in the Northern Prawn Fishery (Commonwealth) is designed to allow for sufficient escapement to ensure adequate spawning biomass (based on historical data). This is achieved through season length and catch-rate thresholds4. The harvest strategy is designed to perform under conditions of substantial variation in biomass that are thought to be largely independent of fishing (Roach et al. 2012).

In 2010, the season ran for approximately 10 weeks (the minimum season length is 6 weeks), with total reported commercial landings of 5642 tonnes (t). This catch is similar to that of the previous two seasons and is approximately 25 per cent above the average catch of the preceding 10 years (2000–09). The commercial catch in 2011 was higher, at 7141 t. These catch levels are indicative of a larger than average biomass, assuming that fishing power has remained relatively constant. Although fishing mortality is thought to be high for White Banana Prawns in some years, the species is thought to be resilient to fishing pressure. Effort expended on White Banana Prawns in the Northern Prawn Fishery (Commonwealth) in 2010 (3146 vessel days) was around 82 per cent of the average effort over the preceding ten years.

The recent historically high commercial catch of White Banana Prawns and a longer than minimum season length (supported by high catch rates) indicate that the management unit is unlikely to be recruitment overfished. The comparatively low effort indicates that fishing mortality is unlikely to cause the management unit to become recruitment overfished (Roach et al. 2012).

Red-legged Banana Prawn

Red-legged banana prawns are a relatively small component of the total prawn catch in the NPF. The bulk of catch is taken in the Joseph Bonaparte Gulf (**Figure 43**). The latest assessment for the stock was released in 2012 (Pláganyi et al. 2012) and includes data up to and including 2011. This model analyses suggest that the resource has dropped below B_{MEY} in the past, has then recovered to the maximum economic yield level, and during the most recent period has increased to above this level.

C.5.5 VALUE OF WILD PRAWNS

According the latest ABARE's status report, for the fishing period 2010-2011, the fishery overall real value has been around $61 million (Woodhams et al. 2011). The net economic return (NER) have gradually increased, becoming positive in 2007–08 and increasing to $21.5 million in 2010–11 (preliminary estimate). This improvement was driven by increasing revenue and relatively stables costs (Woodhams et al. 2011).

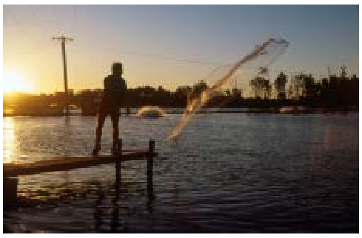
C.5.6 PROJECTED ABUNDANCE CHANGE

The natural history of Banana prawns species is highly dependent of land-sea water cycles in Northern Australia (e.g. Crocos et al. 1983, Robertson 1988). The observed historical climate changes for northern coastal-marine environments are all showing strong increases in temperature, rainfall and sea level, with also significant regional variations (Hadwen et al. 2011). The future predictions for these coastal environments are however still uncertain and current models predictions are suggesting a similar-to-slightly increases on temperature, sea level rainfall, and extreme events, with also high variability and uncertainty (see predictions for NT, Qld at Australia's Future Climate [12]).

For the Banana Prawns species, it is reasonable known that are positively correlated with the Southern Oscillation Index, (NT), rainfall (QLD, GoC), tide levels (GoC), summer flow (GoC), temperature (GoC), winds (GoC). Emigration out of rivers affected by (or lack of) monsoon rainfall (GoC). Temperature extremes and rainfall-flood dynamics explain variation in postlarval and juvenile abundance and survival (QLD), since they are sensitive to temperature and salinity and e.g. survival decreases at higher temperature so likely overall negative impact (Staples and Heales 1991). The expected change in the frequency of monsoon activity and tropical cyclones and resulting rain depressions that provide much of the high-floodwater events in tropical Australia may result affecting the reproduction, growth and emigration cues for bananas. Further, any alteration of flooding regimes may alter also the export of terrigenous-derived nutrients to coastal waters, that these in turn support high primary productivity when prawns are abundant in the these nearshore areas after floods (R. Kenyon pers comm.). River flow thus, as a result of rainfall is highly correlated with offshore commercial catches of banana prawns in the south-eastern Gulf of Carpentaria (Vance et al. 2003). It has been suggested that increased river flow has different effects on different stages of the White Banana Prawn life cycle: high flows can increase emigration of juveniles from estuaries; increased flows can prevent immigration, settlement and survival of post-larvae; and rainfall run-off may increase the overall productivity, through the contribution of increased nutrient input to increased growth and survival rates (Tanimoto et al. 2006).

[12] http://www.climatechangeinaustralia.gov.au/futureclimate.php

C.6 Aquaculture prawns



C.6.1 DISTRIBUTION AND BIOLOGY

The Australian prawn industry is primarily located in North Queensland between Ayr and Port Douglas. Other areas in Queensland include the Gold Coast and Sunshine coast, Bundaberg, and Mackay. In New South Wales, prawn farms are located in the Northern rivers region of Ballina and Coffs Harbour. Prawn farming is also conducted in the Northern territory near Darwin and is under development on the northern coastline of West Australia (Department of Primary Industries and Fisheries 2006). The main species farmed in Australia is the black tiger prawns (*Penaeus monodon*). Other species farmed include the highly valued Kuruma prawns (*P. japonicus*) and Banana prawns (*P. merguiensis*).

The main species farmed, the black tiger prawn, is a tropical to subtropical species that performs best in warm brackish waters although it can also tolerate more saline waters (up to 40 parts per thousand). Due to these characteristics the further North the farm is located the greater the turnover due to higher temperatures. Therefore, operations south of Mackay are limited to one crop a year during the summer because it is too cold in the winter month. On the other hand, operations in the North have the potential to farm two crops (Department of Primary Industries and Fisheries 2006). Black tiger prawns supply the domestic market. Kuruma and Banana species are subtropical and tropical respectively. Kuruma prawns are primarily farmed for exports to Japan whilst Banana prawns are mainly farmed to supply the domestic market.

It takes approximately six months for prawns to grow to be of a harvestable size. Processing is carried out at most prawn farms as they have their own production facilities (Australian Prawn Farmers Association 2012).

C.6.2 THE FISHERY

Prawn farming was established in Queensland in the 1980’s by small scale operators with limited capital and technology. Since then, the industry has grown from 239 tonnes to 3,970 tonnes between the financial years 1988-9 and 2010-11 (Love and Langenkamp 2003). Approximately 900 hectares of ponds and 12 hatcheries produce the latest production of prawns. Prawns are grown in earthen ponds that range from 0.4 to 1.7 hectares and which mostly use intensive farming methods. Average industry productivity is four tonnes per hectare (ABARE fisheries statistics). However, technological improvements regarding genetics, growth technology, environmental and health management has lead to the industry developing rapidly. Two examples of recent developments include, the industry being able to close the life cycle for banana prawn production (Love and Langenkamp 2003) and the introduction of a new breed of black tiger prawns that is more productive, cost effective and tastier (Commonwealth Scientific and Industrial Research Organisation 2013).

C.6.3 FISHERY MANAGEMENT

The National Aquaculture Council has representatives from industry, science and government and works in partnership with the federal government to ensure there is appropriate industry input into the aquaculture policy process (Love and Langenkamp 2003). The Australian prawn farming industry is managed under strict environmental regulations to ensure wastewater discharges of nutrients from farms into the adjacent environment are kept below the regulated threshold. The industry maintains world's best standards of protection for the environment by feeding prawns on low protein diets, use of improved feed management strategies, and using water treatment systems to ensure the water discharged from ponds into the adjacent environment contains negligible to zero levels of nutrients discharged (nitrogen and suspended solids) (Australian Prawn Farmers Association 2002).

C.6.4 PROJECTED ABUNDANCE CHANGE

Scientific development has led to a fast growth in farmed prawn production and is expected to continue to increase into the future. One of the latest developments is CSIRO's new black tiger prawn breed. This new breed is obtaining record high quality prawn yields. Independent Economic forecasts have indicated the new breed of Australian Black Tiger prawn could allow the industry to grow from 5,000 tonnes to 12,500 tonnes and add A$120 million to the value of the industry by 2020 (assuming no further expansion of production area) (CSIRO 2013). Furthermore, the new breed is grown and farmed in drought-proof salt water ponds. Therefore, more frequent droughts under climate change are expected to result in no or little impact to the industry. Furthermore, Australian prawn farming could benefit from temperature increases since the most popular species (e.g., black tiger prawns) are tropical.

The most critical factors that could impact the expansion of production areas are finding sites that have good quality soil and good quality water.

C.6.5 VALUE OF AQUACULTURE PRAWNS

The Australian prawn farmed industry has overall grown in real values from 12 million Australian dollars (AU$) in 1989-90 to 57 million AU$ in 2009-10. Nevertheless, between 1989-90 and 2010-11, the industry reached its highest value in real terms at 101 million AU$ in 2001-02 before declining to 52 million AU$ in 2007-08 (**Figure 46**) (Australian Bureau of Agricultural and Resource Economics 1991-2010; Skirtun et al. 2012; Australian Bureau of Statistics).

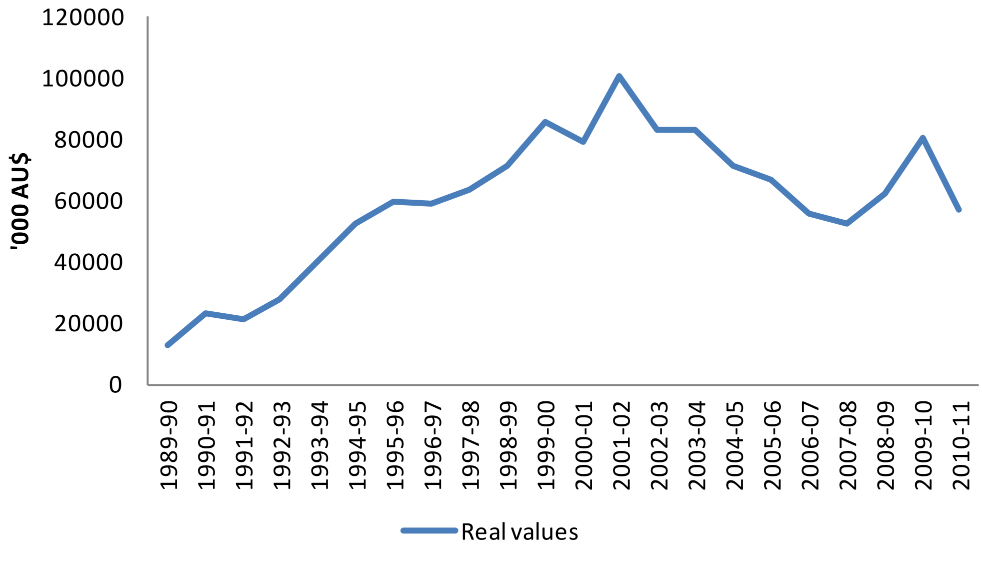


Figure 46 Real values of Australian prawn farming from 1989-90 to 2010-11 (nominal values compiled from ABARE statistics and Food CPI obtained from Australian Bureau of Statistics to convert to real values).

The variation in real values over time relates to the interaction between production and real prices. Whilst production has expanded over time, real prices have continuously declined since the mid 1990s (**Figure 47**) (Australian Bureau of Agricultural and Resource Economics (ABARE) 1991-2010; Skirtun et al. 2012; Australian Bureau of Statistics). Production has increased due to scientific developments regarding genetics, growth technology, environmental and health management that has allowed the industry to cost effectively increase production, from 600 tonnes in 1989-90 to around 4,000 tonnes in 2010-11. Future production is expected to continue to increase in the near future following plans for farming to double in size in the next few years (APFA 2002). On the other hand, real farmed prawn prices have been dropping since the mid 1990's from a peak in 1995-96 (38 AU$/kg) to 14 AU$/kg in 2010-11. The decline in real prices is likely to be due to increase competition in domestic markets following the strengthening of the Australian dollar that has fuelled demand for cheaper prawn imports and made it more profitable for highly valuable Australian wild prawn species (wild tiger, banana and king prawns) to target the domestic market instead of traditional international markets.

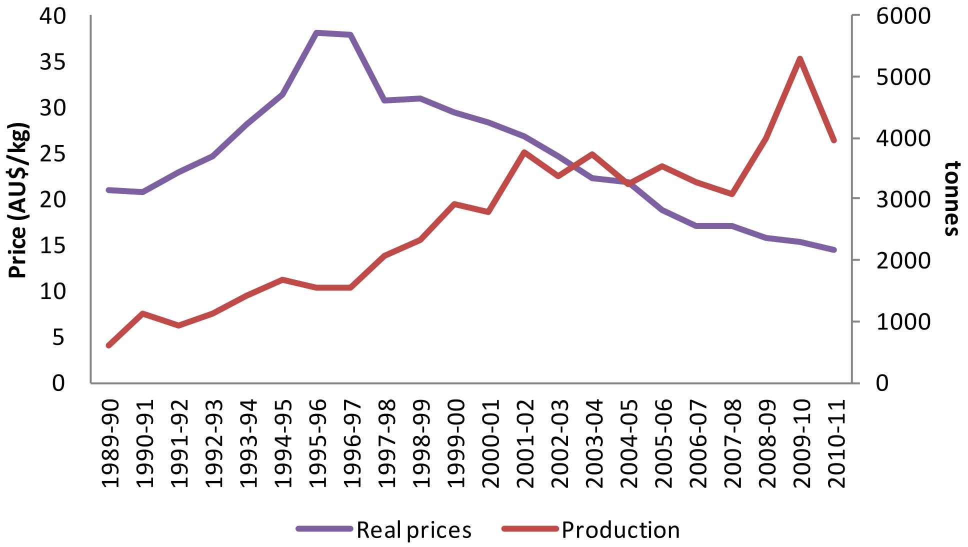


Figure 47 Real prices (AU$/kg, left axis) and production in tonnes (right axis) of Australian farmed prawns (quantities and nominal prices compiled from ABARE statistics and Food CPI obtained from Australian Bureau of Statistics used to convert to real prices).

Figure presents the domestic supply of Australian wild and farmed prawns and import prawns in the domestic market. The development of farmed prawn production is relatively small compared to the fast growth in imports as well as Australian wild prawns. Imports have increased from under 10,562 tonnes in 1989-90 to almost 32,588 tonnes in 2010-11. Domestic supply of wild prawn into the domestic market has been relatively stable at around 13,000 tonnes until 2006-07 but then increased to around 18,000 tonnes in 2009-10 and 2010-11 (**Figure 48**).

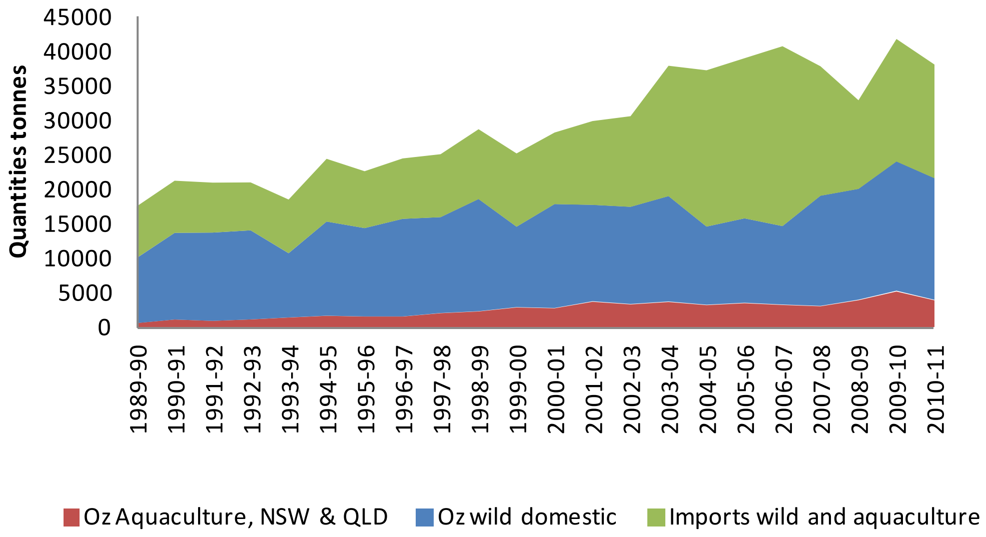


Figure 48 Domestic consumption of Australian farmed and wild prawns and prawn imports (accounting for wild and farmed prawn imports together) from 1989-90 to 2010-11 (compiled from Australian Bureau of Agricultural and Resource Economics Australian Fisheries Statistics 1991-2010; Skirtun et al. 2012).

The future viability of black tiger and other marine prawn farming is likely to depend on the ability of the industry to cost effectively enhance production of high quality prawns so it can remain competitive against supply of cheaper Asian prawns and high quality wild Australian prawns. Future expansion will have the added difficulty of increasingly tighter environmental regulations controlling wastewater discharges. This means that the industry will rely on continuous innovation that will allow expanding production cost effectively so the industry is still profitable whilst also ensuring it is environmentally sustainable.

C.7 Commonwealth Trawl Sector

C.7.1 DISTRIBUTION AND BIOLOGY

There are four principal species caught in the Commonwealth Trawl Sector: Blue Grenadier, Tiger Flathead, Pink Ling and Spotted Warehou. The distribution and biology section will focus on Blue Grenadier, but during the project, the subsequent focus is on the Commonwealth Trawl Sector (CTS) as a whole.

Blue grenadier is found in the south west pacific, namely around southern Australia as well as New Zealand. It occurs at a depth of 200 to 700 metres but can range from 0 to 1000 metres (**Figure 49)**.

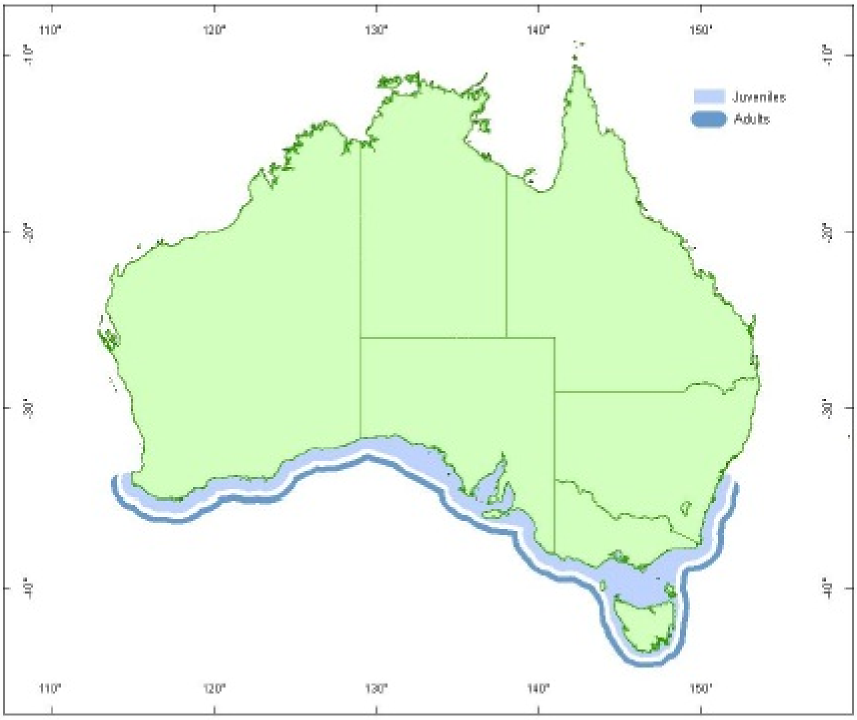


Figure 49 Blue Grenadier distribution (Pecl et al. 2011a).

The juveniles of the species are found inshore while the adults are found on the continental shelf. Adults can live to approximately 25 years with an age at maturity of four to five years for males and four to seven years for females. Spawning occurs off western Tasmania between late May and early September, where females release approx one million eggs, in two to three batches. The fertilised eggs hatch within 60 hours, releasing the pelagic larvae. The duration of the pelagic phase in not known with the population thought to recruit off the western Tasmanian coast. Adult Blue Grenadier form schools on the seabed during the day and disperse into the water column at dusk. During autumn they migrate from their feeding grounds to the primary spawning area off the west coast of Tasmania. They then leave the spawning ground in spring (Pecl et al. 2011a).

C.7.2 THE FISHERY

The Commonwealth Trawl Sector (CTS) is one of four sectors in the Southern and Eastern Scalefish and Shark Fishery (SESSF). It covers the area extending southward from Barranjoey Point (NSW), around the NSW coastline, the Victorian coastline, the Tasmanian coastline to Cape Jervis in South Australia (**Figure 50**). The CTS is the largest sector in terms of catch and value and is one of Australia's oldest commercial fishing sectors (Perks and Vieira 2010).

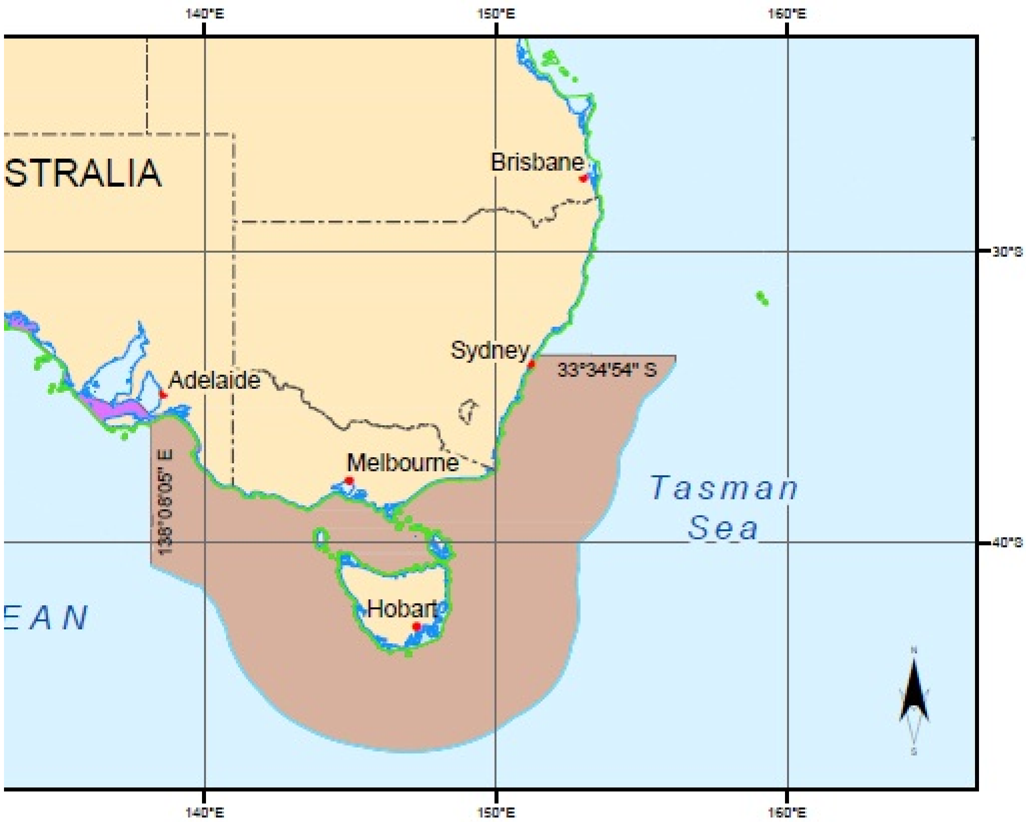


Figure 50 Commonwealth Trawl Sector (AFMA 2005).

Under the Offshore Constitutional Settlement arrangements species and stocks that extend beyond the fishery's boundaries into state waters have been seeded control of SESSF quota managed species to the Australian government. This means catches made in state waters by Australian government endorsed vessels are debited against their SESFF total allowable catch limits. NSW retains jurisdiction over non-trawl fishers along the NSW coastline to 80 nautical miles, trawl fishers north of Sydney to 80 nautical miles and trawl fishers south of Sydney to three nautical miles.

The main fishing method used is otter trawling with some Danish seine boats operating out of Victoria (Perks and Vieria 2010).

C.7.3 FISHERY MANAGEMENT

The SESSF is managed in accordance with the Southern and Eastern Scalefish and Shark Fishery Management Plan 2003. Management of the fishery is mainly based on Total Allowable Catch (TAC) limits and transferable individual quotas. A TAC is set for each of the quota species and to cover incidental catches, non-quota species, this is the total catch by all concession holders that may be taken during that fishing year. The 2012-2013 TAC for Blue Grenadier for 2012-2013 is 2508 tonnes (AFMA 2012b, Perks and Vieria 2010).

C.7.4 PROJECTED ABUNDANCE CHANGE

Blue grenadier may be sensitive to water temperature increases. An increase in water temperature may delay their spawning season (Pecl et al. 2011b).

C.7.5 STATUS OF THE FISHERY

Blue grenadier is classified as not overfished due to the 2011 assessment indication that the female spawning stock biomass was above the 2010 target reference point. The total removals have been less than the long-term recommended biological catch since 2005(Woodhams et al. 2012).

C.7.6 VALUE OF COMMONWEALTH TRAWL SECTOR

The total landings from the Commonwealth Trawl Sector in 2011–12 were 14 437 t. Blue grenadier, flathead, pink ling and silver warehou continued to account for about two-thirds of the catch by value. Blue grenadier and pink ling catches declined from the previous season, whereas flathead and silver warehou catches increased. Only 42 per cent of the silver warehou TAC was caught, whereas around 87 per cent of the blue grenadier TAC was caught (Woodhams et al. 2012).

Blue grenadier and flathead remained the dominant species of the Commonwealth Trawl Sector in value terms in the 2010–11 financial year; they were valued at $10.7 million and $13.9 million, respectively. For blue grenadier, this represents a 37 per cent decrease relative to 2009–10 ($16.8 million). Another key change in 2010–11 was a 48 per cent increase in the value of pink ling landings, from $4.9 million in 2009–10 to $7.1 million in 2010–11, due to increases in both catch and price. However, this follows a previous decline between 2008–09 and 2009–10 of similar proportions. Orange roughy was associated with a large decline in value, from $3.1 million in 2009–10 to $0.6 million in 2010–11, which was driven by large falls in both catch and price (Woodhams et al. 2012).

Appendix D Project publications

The project publication output includes seven published, submitted or planned peer-reviewed papers, five popular articles, four conference presentations, and seven fact sheets.

D.1 Peer-reviewed papers

D.1.1 PUBLISHED OR IN PRESS

1. Fleming, A., Hobday, A. J., Farmery, A., van Putten, E. I., Pecl, G. T., Green, B. S. & Lim-Camacho, L. in press Climate change risks and adaptation options across Australian seafood supply chains - a preliminary assessment. *Climate Risk Management*. (**Paper 1**)
2. Norman-Lopez, A., Pascoe, S., Thebaud, O., van Putten, E. I., Innes, J., Jennings, S., Hobday, A. J., Green, B. & Plaganyi, E. 2013 Price integration in the Australian rock lobster industry: implications for management and climate change adaptation. *Australian Journal of Agriculture and Resource Economics*, doi: 10.1111/1467-8489.12020. (**Paper 3**)

D.1.2 SUBMITTED

3. van Putten, E. I., Farmery, A., Green, B. S., Hobday, A. J., Lim-Camacho, L. & Norman-López, A. in review The supply chains of two Australian rock lobster fisheries under a changing climate. *Journal of Industrial Ecology*. (**Paper 2**). Submitted June 20, 2013
4. Plaganyi, E. E., van Putten, E. I., Thebaud, O., Hobday, A. J., Innes, J., Lim-Camacho, L., Norman-Lopez, A., Bustamante, R. H., Farmery, A., Fleming, A., Frusher, S., Green, B. S., Hoshino, E., Jennings, S., Pecl, G., Pascoe, S., Schrobback, P. & Thomas, L. in review A quantitative metric to identify critical elements within seafood supply networks. *PLoS ONE*. (**Paper 4**) submitted Sept 18, 2013
5. Norman-Lopez, A., Innes, J., Pascoe, S., Hobday, A. J. & Plagányi, E. E. in review Long run price flexibilities for prawns in the Australian domestic market and the implications for industry growth. *Marine Resource Economics*. (**Paper 5**), submitted Oct 2, 2013.
6. Norman-Lopez, A., Pascoe, S., Thebaud, O., Mwebaze, P., Hobday, A. J. & van Putten, E. I. in review Price effects on supplies of Australian rock lobster in domestic and international markets. *Journal of Agricultural Economics*. (**Paper 6**)
7. Lim-Camacho, L., Hobday, A. J., Bustamante, R. H., Farmery, A., Fleming, A., Frusher, S., Green, B. S., Norman-Lopez, A., Pecl, G., Plaganyi, E. E., Schrobback, P., Thebaud, O., Thomas, L. & van Putten, E. I. in review Facing the wave of change: Stakeholder perspectives on climate adaptation for Australian seafood supply chains. *Regional Environmental change*. (**Paper 7**)
8. Hobday, A. J., Bustamante, R. H., Farmery, A., Fleming, A., Frusher, S., Green, B. S., Lim-Camacho, L., Norman-Lopez, A., Pecl, G. T., Plaganyi, E. E., Thebaud, O., Thomas, L. & van Putten, E. I. in preparation Growth opportunities for marine fisheries and aquaculture industries in a changing climate. In *NCCARF book* (ed. J. Palutikof, J. Barnett, S. L. Boulter & D. Rissik). (**Paper 8**)

D.1.3 ASSOCIATED PAPERS

These four papers discuss economic aspects of the case study species (e.g. oyster) or species not considered in this project (e.g. abalone), but included project team members.

- Farmery A, Gardner C, Green B and Jennings S (in revision) Unintended consequences of management decisions on the environmental footprint of seafood.
- Hoshino E et al. (in revision) Price relationships for imported abalone in the Japanese market.
- Hoshino E et al. (in preparation) Price relationships for imported Australian abalone in the Hong Kong market.
- Schrobback P, Pascoe S and Coglan L (in press) Impacts of introduced aquaculture species on markets for native marine aquaculture products: The case of edible oysters in Australia. Aquaculture Economics & Management

D.2 Popular articles

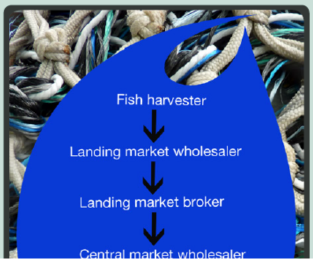
The project team published a total of five popular articles: three popular articles as required by the project milestone agreement and according to the communication and extension plan, a project overview fact sheet, and a posting to an industry blog site. We also completed a set of six industry fact sheets presenting results of the project.

Marine Adaptation Bulletin, Autumn 2012 (vol, 4 #1) - General project overview

Creating Future Opportunities for Marine Fisheries and Aquaculture Across the Value Chain

Dr Alistair Hobday, CSIRO, Marine Atmospheric Research Climate Adaptation Flagship – Adaptation Research Grant Project Principle Investigator. Project: Growth opportunities & critical elements in the value chain for wild fisheries & aquaculture in a changing climate. Project number: 2011/233 FRDC-DCCEE.

Fisheries and aquaculture businesses in Australia are well placed for the future. Environmental stewardship is on the rise, over-capacity in wild fisheries has largely been removed and markets are growing for wild and cultured products. Challenges remain, however, such as access to suitable workforce, fuel prices, international competition and imports, social perceptions regarding sustainability, and the additional uncertainty created by climate change. Recent studies have suggested that productivity of Australia's regional seas will rise due to climate change this century[1], and as a result, increases in the potential yield of well-managed fisheries and their economic benefits should be possible[2]. There are



A new project, funded under the DCCEE-FRDC-NCCARF Marine National Adaptation Research Plan, is seeking to explore some of the opportunities for growth in Australian fisheries and aquaculture along the value chain. This two year project, led by CSIRO's Climate Adaptation Flagship in partnership with University of Tasmania's Institute for Marine and Antarctic studies, will first document supply chains for selected fisheries, including the Tasmanian rock lobster, Torres Strait rock lobster, and NSW oyster culture. Life cycle analysis (LCA), a technique often used to assess environmental impacts associated with all the stages of a product's passage along the supply chain (i.e., from raw material extraction through materials processing, manufacture, distribution, use,

FISH (FRDC magazine) December 2012 (vol 20, #4). – explaining social perception study. Available at: http://frdc.com.au/knowledge/publications/fish/Documents/FISH%2020-4%20Climate%20drivers%20for%20supply-chain%20change.pdf

By Aysha Fleming and Alistair Hobday, CSIRO

FRDC Research Code: 2011/233
More information: Aysha Fleming, aysha.fleming@csiro.au; Alistair Hobday, alistair.hobday@csiro.au; www.frdc.com.au/environment/climate_change/pages/default.aspx

Climate drivers for supply-chain change

All around Australia we are observing the effects of climate change on the marine environment. Warming ocean temperatures, altered currents, more intense cyclones and marine heatwaves are affecting the distribution and availability of fish.

These new conditions, together with a growing population and increased demand for seafood, mean fishery supply chains need to change.

When it comes to climate change research, the biophysical end of the supply chain has received the most attention, but several joint potential risks, and the support that might be needed for each industry.

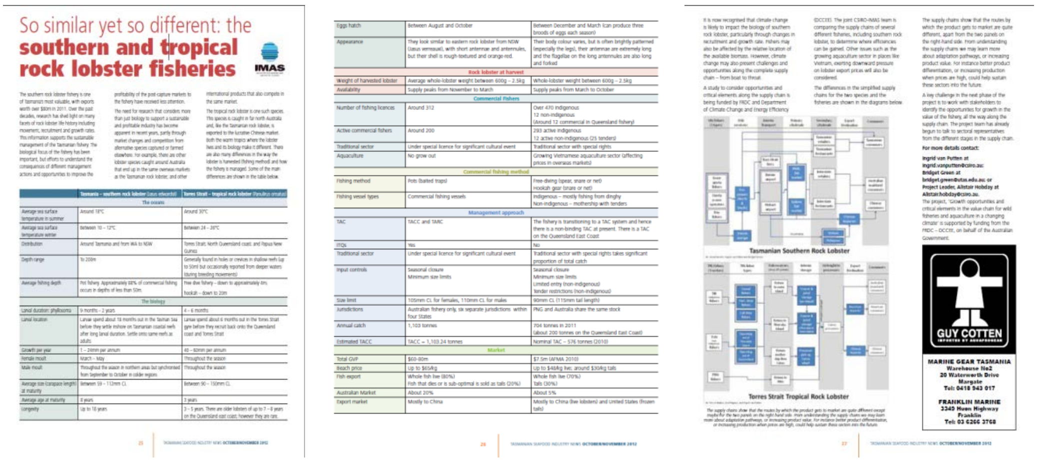
Australian supply chains vary widely; some involve direct sales to the consumer, others require multiple processing and transport steps. They also span both national and international markets. Commonalities do exist, but several industry-specific issues and opportunities have been identified.

The interviews explored both climate and non-climate issues (Figure 1) and all participants highlighted the need for more collaboration to produce better marketing

- management of fuel, transport and energy prices;
- management of species changes in location and abundance;
- monitoring and research of climate effects (temperature, acidification, sea level); and
- management of extreme events such as cyclones and heavy rain.

In most cases participants across the supply chain see themselves as adaptable to climate change, either because of the resilience of the target species or the skills and abilities of people involved. However,

Fishing Today (Tasmanian Seafood Industry Magazine) November 2012 – comparing rock lobster fisheries.

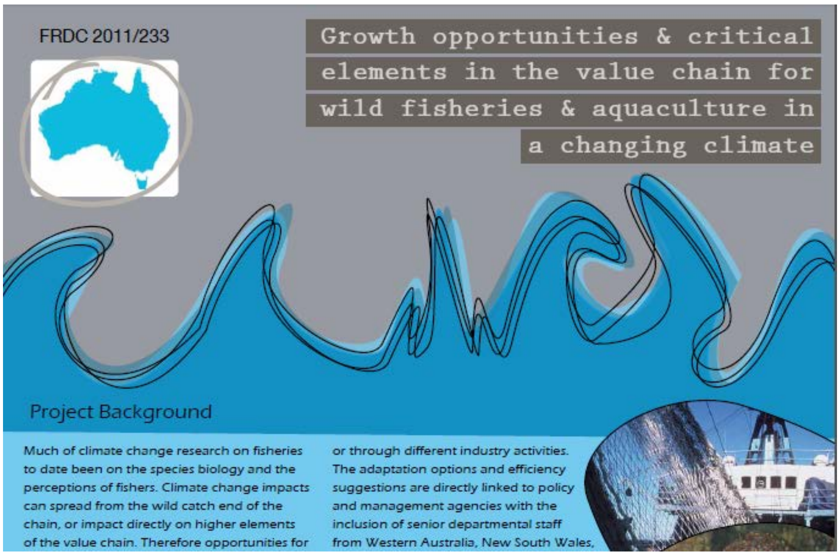


Oyster Australia blog site (http://oystersaustraliablog.org.au/)

blog posted February 2013 about the project

D.3 Project fact sheets

Project overview fact sheet (produced as part of Jenny Shaw's NARP project).



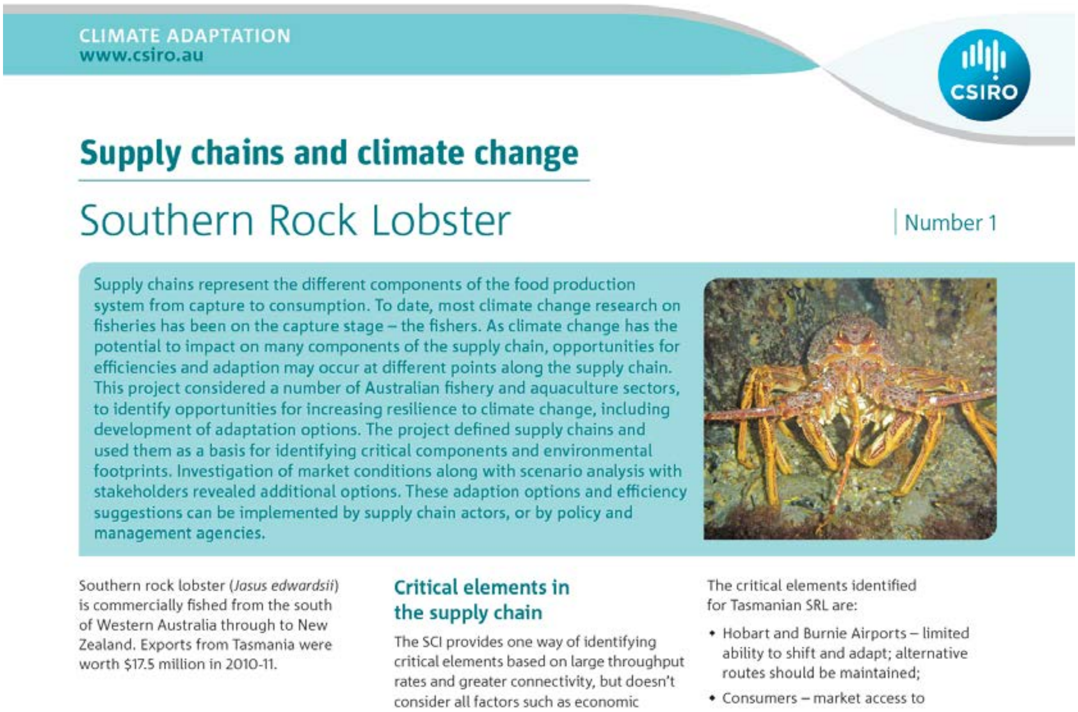
FRDC 2011/233

Growth opportunities & critical elements in the value chain for wild fisheries & aquaculture in a changing climate

Project Background

Much of climate change research on fisheries to date been on the species biology and the perceptions of fishers. Climate change impacts can spread from the wild catch end of the chain, or impact directly on higher elements of the value chain. Therefore opportunities for or through different industry activities. The adaptation options and efficiency suggestions are directly linked to policy and management agencies with the inclusion of senior departmental staff from Western Australia, New South Wales,

Facts sheets summarizing project results. A total of six final fact sheets were produced and distributed to industry representatives. An example of one fact sheet is presented below, and all six are included as supplementary material to the project.



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Supply chains and climate change

Southern Rock Lobster | Number 1

Supply chains represent the different components of the food production system from capture to consumption. To date, most climate change research on fisheries has been on the capture stage – the fishers. As climate change has the potential to impact on many components of the supply chain, opportunities for efficiencies and adaption may occur at different points along the supply chain. This project considered a number of Australian fishery and aquaculture sectors, to identify opportunities for increasing resilience to climate change, including development of adaptation options. The project defined supply chains and used them as a basis for identifying critical components and environmental footprints. Investigation of market conditions along with scenario analysis with stakeholders revealed additional options. These adaption options and efficiency suggestions can be implemented by supply chain actors, or by policy and management agencies.

Southern rock lobster (*Jasus edwardsii*) is commercially fished from the south of Western Australia through to New Zealand. Exports from Tasmania were worth $17.5 million in 2010-11.

Critical elements in the supply chain

The SCI provides one way of identifying critical elements based on large throughput rates and greater connectivity, but doesn't consider all factors such as economic

The critical elements identified for Tasmanian SRL are:

- Hobart and Burnie Airports – limited ability to shift and adapt; alternative routes should be maintained;
- Consumers – market access to

D.4 Conference presentations

A total of four conference presentations have been completed.

Norman et al, (2013) The implication of climate change in Australian seafood markets – the case of prawns. AARES (Australian Agriculture and Resource Economics Society), Sydney, 6th-8th February 2013

- The aim of this analysis is to identify whether an increase in the supply of low price farmed prawn imports from South East Asia into Australia's market will impact the prices received by Australia's wild and farmed prawn producers. Climate change projections suggest South East Asia's prawn farmers could expand production and hence exports due to sea level rise increasing mangrove areas. Increased levels of prawn imports have the potential to reduce the prices received by Australian domestic producers if prawns from different locations and production methods are considered substitutes. We use Australian wild and farmed prawn prices and import prawn prices to conduct a co-integration analysis of market integration in Australia's prawn industry.

Hobday et al, (2013) From fish to dish – future opportunities for Australian fisheries and aquaculture. NCCARF 2013, July 2013, Sydney. http://www.nccarf.edu.au/conference2013/

- Climatic changes in the marine environment are occurring around Australia. These changes impact the distribution and availability of fish and together with a growing population and increased demand for seafood, it is clear that adaptation across fishery supply chains is needed. In this marine NARP project we take this broader perspective to ensure that opportunities across the chain are recognized. We modeled supply chains for seven fisheries and aquaculture business and explored opportunities and weaknesses. This multi-disciplinary team developed holistic solutions and participatory approaches with stakeholders, guided by findings from different analytical tools, including life cycle assessment, market demand and integration, and network analysis. While Australian supply chains vary widely, from direct sales to the consumer or via multiple processing and transport steps to both national and international markets, commonalities do exist, as well as industry-specific issues and opportunities. In interviews, both climate and non-climate issues were highlighted and participants identified that more collaboration is needed to produce better marketing strategies, raise awareness of sustainable practices and combat product substitution. A particular focus highlighted for policy development was the need to simplify complex or outdated regulations that may contradict current industry priorities, such as improving efficiency. We found that climate change impacts are well understood at the harvest stage, yet are not a strong driver for change higher up the chain, despite evidence for potential impacts and disruption to supply chains. Holistic adaptation planning along the supply chain, underpinned by targeted information and policy for the non-harvest elements, is needed.

Farmery et al, (2013). LCA analysis for Australian rock lobster fisheries. NCCARF 2013, July 2013, Sydney. http://www.nccarf.edu.au/conference2013/

- Adaptation to climate change must occur across food supply chains. For seafood, the management focus for climate change has been on biological impacts in marine ecosystems and resilience. Reducing the environmental footprint of seafood, particularly the carbon footprint, across the supply chain is a new concept for seafood sustainability. The influence of management decisions on carbon emissions has not been considered in regards to seafood sustainability and adaptation options. We used life cycle assessment (LCA) to measure the environmental footprint of the Southern rock lobster (SRL). The LCA results were analysed under a series of management scenarios to determine impacts of marine resource management decisions on the environmental footprint of the SRL. We found significant changes in the overall footprint of the SRL under different management scenarios. Reducing the harvest rate to maximise economic benefit (target MEY) decreased the carbon footprint. Surprisingly, management decisions based on increasing marine protected areas increased the carbon footprint of the fishery by 8% in one case. The unintended consequences of management changes suggest that in a future of carbon accounting and increased regulation of CO_2 emissions, marine resource decision making should not be made in isolation of downstream impacts. Management decisions in fisheries can be a tool to reduce environmental impacts of seafood, including carbon emissions, as fuel use at capture is typically the dominant input across the life cycle. Fisheries managed under low harvest rates are better placed to incorporate these indicators than fisheries that are not well managed or are managed for objectives such as maximum food or employment.

Hobday A. J. (2013). From fish to dish – growth opportunities for Australian fisheries and aquaculture. Seafood Directions, Port Lincoln, Oct 27-30, 2013

- Climatic changes in the marine environment are occurring around Australia. These changes impact the distribution and availability of fish and together with a growing population and increased demand for seafood, it is clear that adaptation across fishery supply chains is needed. In this marine NARP project we take this broader perspective to ensure that opportunities across the chain are recognized. We modelled supply chains for seven fisheries and aquaculture business and explored opportunities and weaknesses. This multi-disciplinary team developed holistic solutions and participatory approaches with stakeholders, guided by findings from different analytical tools, including life cycle assessment, market demand and integration, and network analysis. While Australian supply chains vary widely, from direct sales to the consumer or via multiple processing and transport steps to both national and international markets, commonalities do exist, as well as industry-specific issues and opportunities. In interviews, both climate and non-climate issues were highlighted and participants identified that more collaboration is needed to produce better marketing strategies, raise awareness of sustainable practices and combat product substitution. A particular focus highlighted for policy development was the need to simplify complex or outdated regulations that may contradict current industry priorities, such as improving efficiency. We found that climate change impacts are well understood at the harvest stage, yet are not a strong driver for change higher up the chain, despite evidence for potential impacts and disruption to supply chains. Holistic adaptation planning along the supply chain, underpinned by targeted information and policy for the non-harvest elements, is needed.

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Section 4: Need

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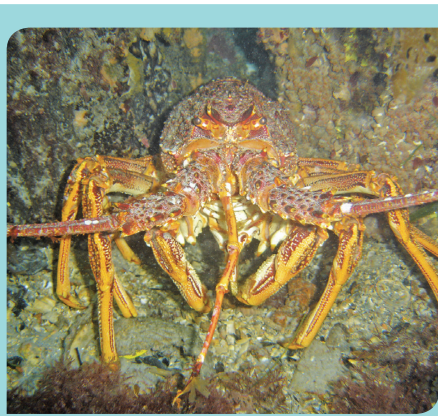
Supply chains and climate change

Southern Rock Lobster

Number 1

Supply chains represent the different components of the food production system from capture to consumption. To date, most climate change research on fisheries has been on the capture stage – the fishers. As climate change has the potential to impact on many components of the supply chain, opportunities for efficiencies and adaption may occur at different points along the supply chain. This project considered a number of Australian fishery and aquaculture sectors, to identify opportunities for increasing resilience to climate change, including development of adaptation options. The project defined supply chains and used them as a basis for identifying critical components and environmental footprints. Investigation of market conditions along with scenario analysis with stakeholders revealed additional options. These adaption options and efficiency suggestions can be implemented by supply chain actors, or by policy and management agencies.



Southern rock lobster (*Jasus edwardsii*) is commercially fished from the south of Western Australia through to New Zealand. Exports from Tasmania were worth $17.5 million in 2010-11.

Critical elements in the supply chain

The SCI provides one way of identifying critical elements based on large throughput rates and greater connectivity, but doesn't consider all factors such as economic efficiency or risk of being perturbed.

The critical elements identified for Tasmanian SRL are:

- Hobart and Burnie Airports – limited ability to shift and adapt; alternative routes should be maintained;
- Consumers – market access to consumers is an important component for supporting and building resilience

Tasmanian Southern Rock Lobster (SRL)

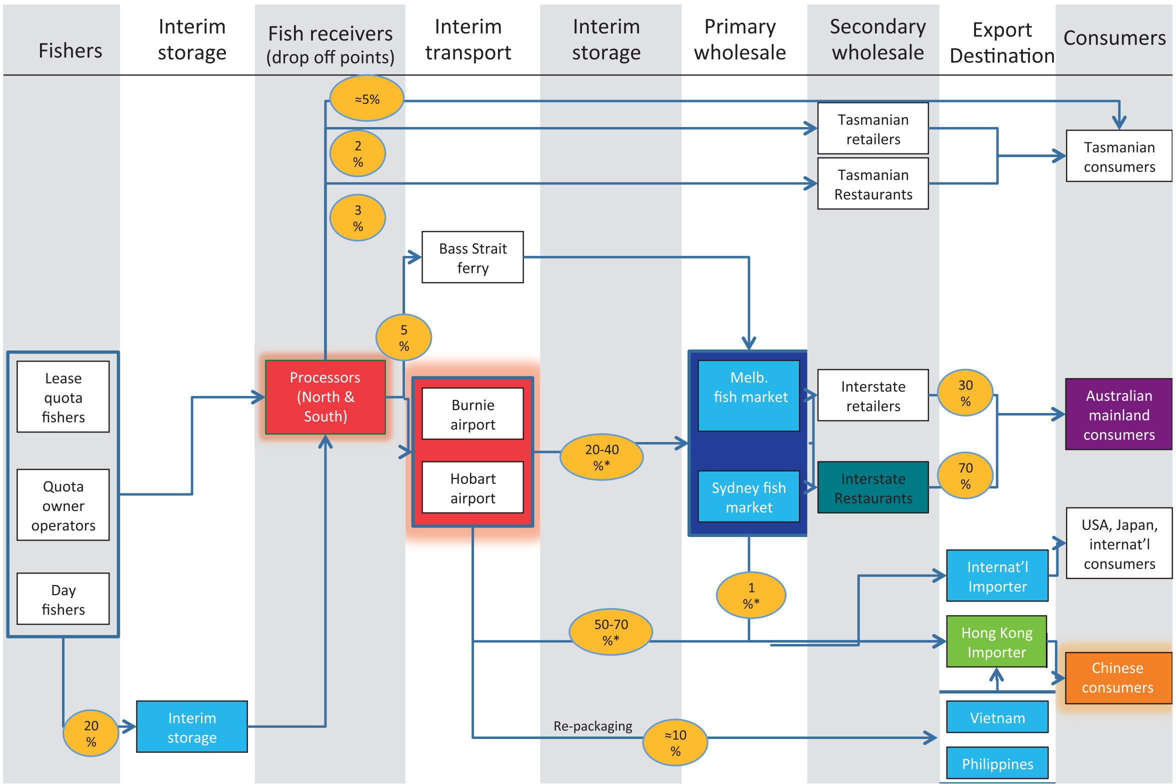


FIGURE 1 **SRL supply chain, showing the relative flow of product with colour coding to highlight critical elements. Individual Supply Chain Index (SCI) scores for each element in the supply chains are coloured when they represent 1% or more of the total score. From highest to lowest scores, the colour coding used is red (>20%)-orange-green-blue-purple. Additional highlights to the red and orange boxes emphasize the critical elements. The supply chain components are based on common templates used for consistency for all fisheries considered in this project.**

– adaptation efforts to enhance market access are important

- Processors – strengthening this component, for example by vertical integration with fishers, can increase the resilience of the chain.

Environmental footprint for the supply chain

Life cycle assessment (LCA) takes into account the environmental footprint of the supply chain. It includes the environmental consequences of the inputs such as the production of the fishing gear, the production of fuel and transportation.

The main LCA categories for Tasmanian SRL are:

- Global warming – international airfreight and fuel are the major contributors
- Cumulative energy demand (CED) – bait and international transport are major contributors
- Water use – bait packaging and the production of diesel and steel traps are the major uses in the capture phase; in the processing phase the wash down of the processing facility contributes to the majority of water use.

Market analyses

Market analyses consider the relationships between domestic and international markets, volume of product and price and completion from other producers.

The main market analyses results for SRL are:

- Consumers in the Hong Kong market see Australian SRL as close substitutes to other Australian rock lobster species; and prices of the different species follow similar trends over time. Links between prices of different rock lobster species in the Hong Kong market suggests that coordinating fisheries management and development strategies across species and States will be advantageous.

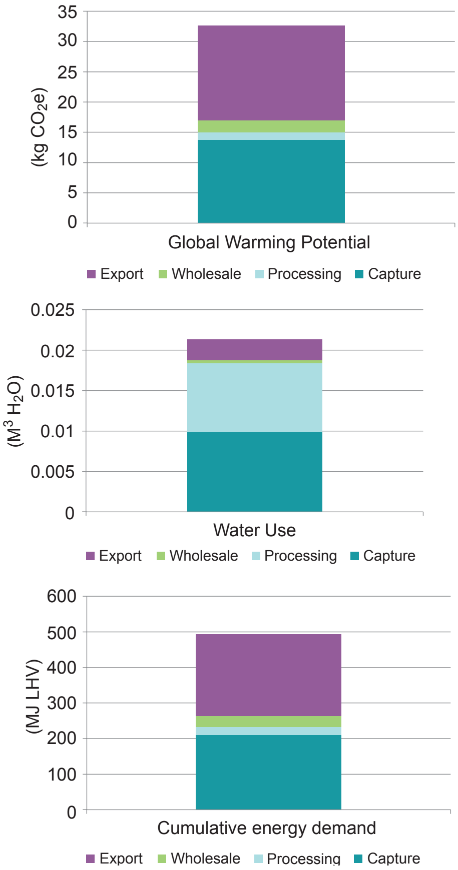


FIGURE 2 **Contribution by category to the life cycle impacts of 1 kg of SRL exported live from Tasmania.**

- The adaptive capacity of Australia's rock lobster industry is dependent on allocating product between different markets. For the different scenarios considered, the industry was able to minimise losses or increase revenues by allocating supply between the Hong Kong (China) and the domestic markets. When the scenario restricted supply to the Hong Kong market major losses resulted. Future adaptation strategies should concentrate on reducing this risk by both reducing the likelihood of access to the Chinese market being restricted (e.g. via stronger trade agreements), and by attempting to diversify the markets they supply, to mitigate the potential impact.

Future adaptation options

Two potential future scenarios based on literature reviews, expert opinion, stakeholder interviews and related projects were presented to stakeholders.

Scenario one
Potential supply change

> Continued large scale declines in recruitment across south eastern Australia leading to further stock size reduction in north and northeast Tasmania in particular, but also in west and southwest Tasmania.

Scenario two
Potential demand change

> Sudden and prolonged export market closure due to any of the following reasons: access routes closed; quality controls; import restrictions; health issues.

The perceived adaptation options of stakeholders, who considered their industry to be adaptable, were generally short term in nature and targeted at the capture (fisher) end of the chain. Managing catch rates was seen as a first point of action for both scenarios, largely because it is a strategy that is currently used to manage short term supply and demand disruptions. Longer-term adaptation options were also put forward, such as shifting fishing areas (Scenario 1) and diversifying markets and building collaborative relationships with customers (Scenario 2), but additional work to explore these options with integrated modelling is warranted.

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Supply chains and climate change

Wild (banana) prawns

Number 2

Supply chains represent the different components of the food production system from capture to consumption. To date, most climate change research on fisheries has been on the capture stage – the fishers. As climate change has the potential to impact on many components of the supply chain, opportunities for efficiencies and adaption may occur at different points along the supply chain. This project considered a number of Australian fishery and aquaculture sectors, to identify opportunities for increasing resilience to climate change, including development of adaptation options. The project defined supply chains and used them as a basis for identifying critical components and environmental footprints. Investigation of market conditions along with scenario analysis with stakeholders revealed additional options. These adaption options and efficiency suggestions can be implemented by supply chain actors, or by policy and management agencies.

The Northern Prawn Fishery (NPF) is located off Australia's northern coast, between Cape York (QLD) and Cape Londonderry (WA), occupying 771,000 square kilometres. In 2010-2011 the Northern Prawn Fishery had a gross value of production of $94.8 million (Skirtun *et al*). The value of the fishery fluctuates widely, and is subject to a number of external factors including environmental drivers, foreign exchange rates and export market conditions.

Banana Prawn (Northern Prawn Fishery)

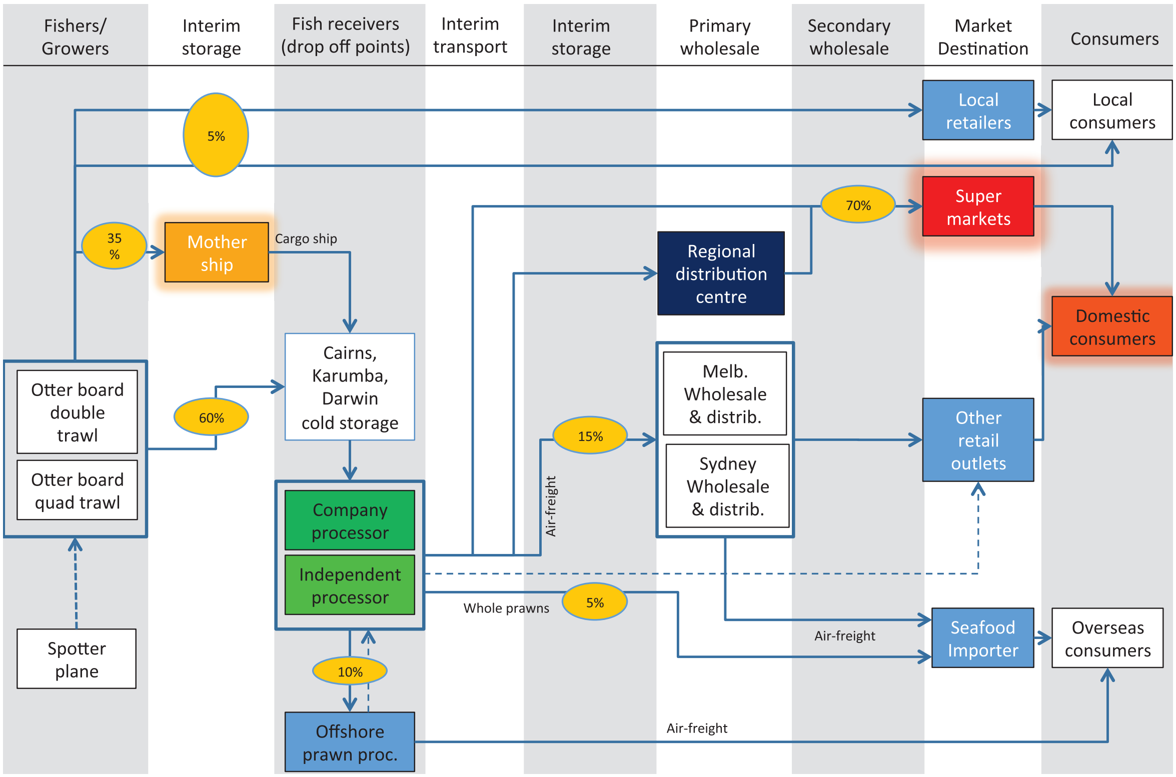

FIGURE 1 **NPF supply chain, showing the relative flow of product with colour coding to highlight critical elements. Individual Supply Chain Index (SCI) scores for each element in the supply chains are coloured when they represent 1% or more of the total score. From highest to lowest scores, the colour coding used is red (>20%)-orange-green-blue-purple. Additional highlights to the red and orange boxes emphasize the critical elements. The supply chain components are based on common templates used for consistency for all fisheries considered in this project.**

Critical elements in the supply chain

The SCI provides one way of identifying critical elements based on large throughput rates and greater connectivity, but doesn't consider all factors such as economic efficiency or risk of being perturbed.

For Northern Prawn Fishery banana prawns, the supermarkets and the domestic consumers they supply were the identified as critical elements. This highlights that is it important to secure a good working arrangement with the supermarkets. For example, the stability of the supply chain can be improved by focussing effort on determining what factors (e.g. steady supply minimum volumes of product) are necessary to maintain this as a successful link. In general the banana prawn supply chain showed a spread of key elements across the chain, and hence an ability to change and adapt connection in response to exogenous shocks.

Environmental footprint for the supply chain

Life cycle assessment (LCA) takes into account the environmental footprint of the supply chain. It includes the environmental consequences of the inputs such as the production of the fishing gear, the production of fuel and transportation.

The main LCA components for NPF are:

- Global warming potential – diesel at the capture stage;
- Cumulative energy demand (CED) – diesel at the capture stage;
- Water use – the wash down of the processing facility.

The capture stage was the main overall contributor accountng for 80% of impacts.

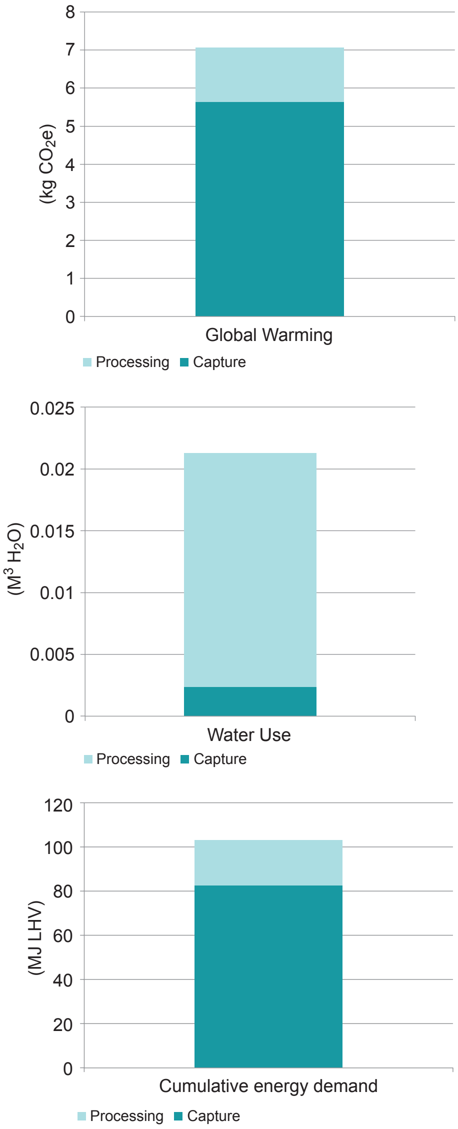

FIGURE 2 **Contribution by category to the life cycle impacts of 1 kg of frozen Banana prawns at wholesale.**

Market analyses

Market analyses consider the relationships between domestic and international markets, volume of product and price and completion from other producers.

Economic analysis regarding the long run price flexibilities for prawn species in the Australian domestic market demonstrated:

- Co-integration between Australian wild and farmed prawns and prawn import prices;
- Imports will depress the price received by Australian prawns, it will not necessarily be the other way around;
- Import prawns are lower value than Australian prawns.

Future adaptation options

Two potential future scenarios based on literature reviews, expert opinion, stakeholder interviews and related projects were presented to stakeholders.

Scenario one
Potential supply change
> Long term trend to higher floods and wetter summers increase recruitment, growth and migration to fishing grounds.

Scenario two
Potential demand change
> Long term increase in competition from imported and farmed prawns.

The adaptation options and stakeholder interviews showed that:

- Improving fishing operations to achieve increased efficiencies and take advantage of economies of scale as volume of supply increases is a potential adaptation option;
- Stakeholders had mixed responses to a potential increase in supply of banana prawns as shown by concern by some for oversupplying a market resulting to reduced prices and overall profitability, while others feel that the market is undersupplied, and has the potential to increase quite significantly;
- A key concern is a decrease in price as the volume of imported and farmed product in the market poses stronger competition to wild-caught prawns, resulting to an overall contraction of the industry.

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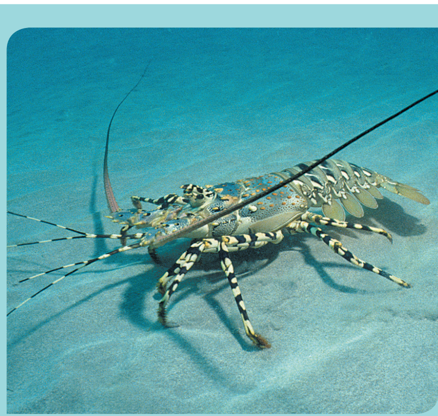
Supply chains and climate change

Tropical Rock Lobster (Torres Strait Fishery)

Number 3

Supply chains represent the different components of the food production system from capture to consumption. To date, most climate change research on fisheries has been on the capture stage – the fishers. As climate change has the potential to impact on many components of the supply chain, opportunities for efficiencies and adaption may occur at different points along the supply chain. This project considered a number of Australian fishery and aquaculture sectors, to identify opportunities for increasing resilience to climate change, including development of adaptation options. The project defined supply chains and used them as a basis for identifying critical components and environmental footprints. Investigation of market conditions along with scenario analysis with stakeholders revealed additional options. These adaption options and efficiency suggestions can be implemented by supply chain actors, or by policy and management agencies.



The Torres Strait Tropical Rock Lobster (*Panulirus ornatus*) fishery extends from the tip of Cape York to the northern border of the Torres Strait Protected Zone. It is part of the Commonwealth fisheries and is currently the largest commercial fishery in the Torres Strait in terms of catch (704 tonnes in 2010-11) and value (estimated to be $24 million in 2010-11).

Critical elements in the supply chain

The SCI provides one way of identifying critical elements based on large throughput rates and greater connectivity, but doesn't consider all factors such as economic efficiency or risk of being perturbed.

The critical element identified for the TRL is:

- The US and Chinese markets – the need to reduce uncertainty in supplying

Torres Strait Tropical Rock Lobster (TRL)

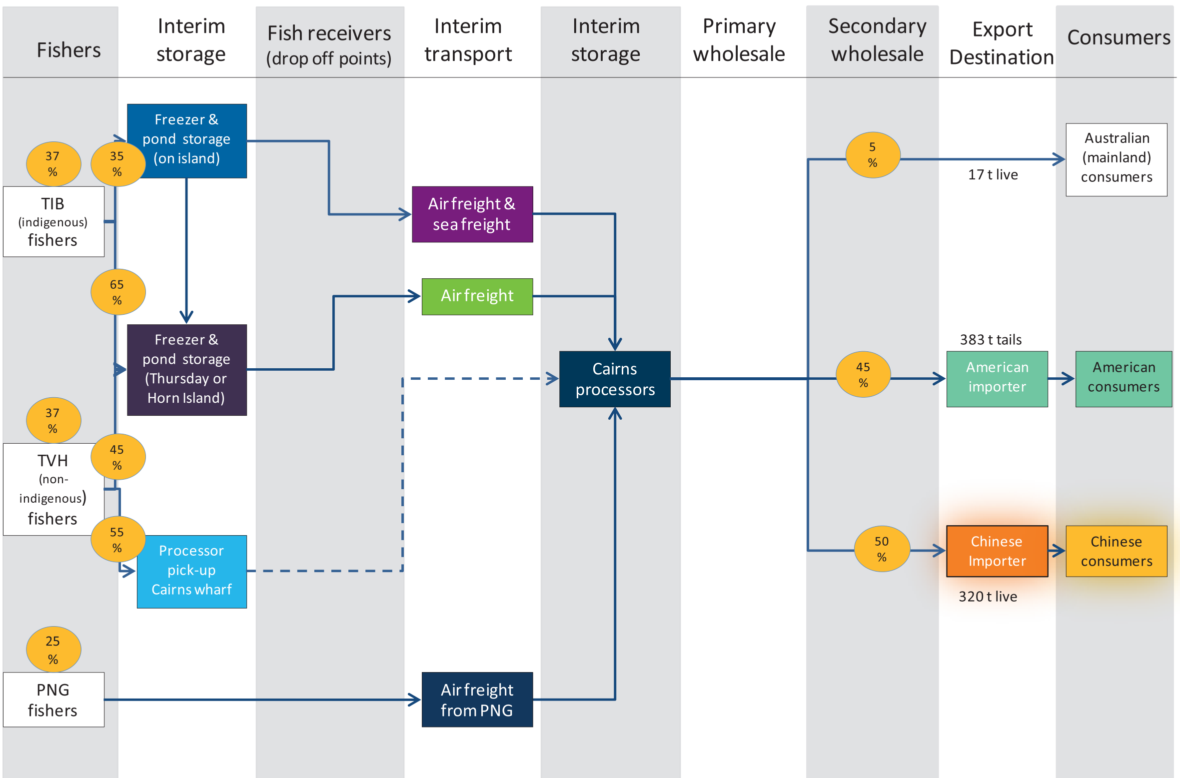


FIGURE 1 **TRL supply chain, showing the relative flow of product with colour coding to highlight critical elements. Individual Supply Chain Index (SCI) scores for each element in the supply chains are coloured when they represent 1% or more of the total score. From highest to lowest scores, the colour coding used is red (>20%)-orange-green-blue-purple. Additional highlights to the red and orange boxes emphasize the critical elements. The supply chain components are based on common templates used for consistency for all fisheries considered in this project.**

these markets by strengthening and maintaining relationships.

Environmental footprint for the supply chain

Life cycle assessment (LCA) takes into account the environmental footprint of the supply chain. It includes the environmental consequences of the inputs such as the production of the fishing gear, the production of fuel and transportation.

The TRL fishery has a total of five fisher typologies based on fisher type, fishing activity and freight and market destination. The main LCA component of TRL (total catch) is:

- Global warming potential – greatest in the export phase and lowest in the processing phase with different contributions depending on the fisher type.

Market analyses

Market analyses consider the relationships between domestic and international markets, volume of product and price and completion from other producers.

The main market analyses results for TRL show:

- Based on demand analysis, the TRL product is seen to be interchangeable with other Australian rock lobster species by the Hong Kong market and while specific prices vary between species, increases and decreases in prices are expected to follow similar trends;
- The US market for tails, while an important market, is unlikely to absorb the extra product from the live market if the live market declines.

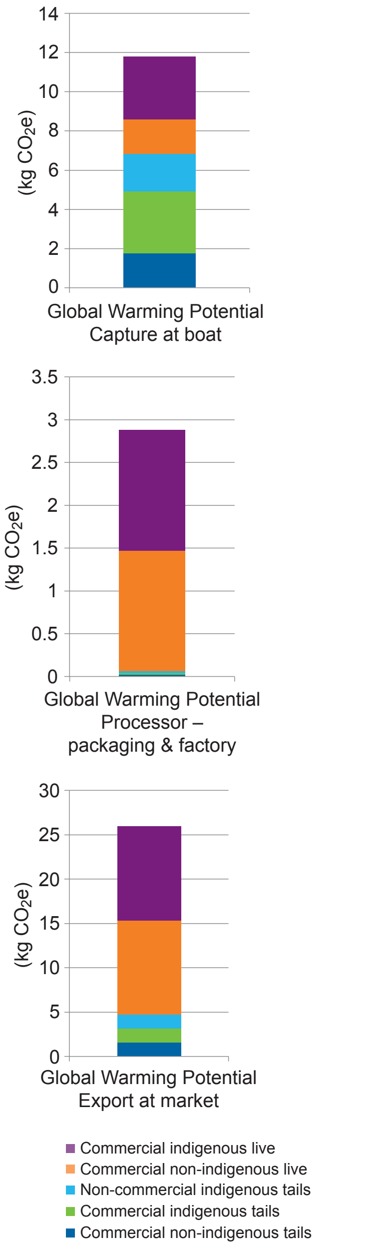


FIGURE 2 **Global warming potential (kg CO_2e per kg lobster) for five fisher-types in the tropical rock lobster fishery.**

Future adaptation options

Two potential future scenarios based on literature reviews, expert opinion, stakeholder interviews and related projects were presented to stakeholders.

Scenario one
Potential supply change

> Small islands are impacted by sea level rise consequently shifting islander population. Fishers will have to travel further to reach the previous catching grounds causing higher travel costs to islander fishers. The overall effects will be decreased supply due to lower catches from previous grounds (due to increase fishing cost) and lower catches from closer grounds due to localised depletion).

Scenario two
Potential demand change

> Increased international competition due to change in geographical spread of production with PNG increasing production (wild catch). Overall there is increased international competition from both non-Australian wild and farmed product increasing quantities available and reducing average prices.

The adaptation options and stakeholder interviews showed that:

- Given the relatively small area in the Torres Strait, the non-traditional inhabitant fishers are seen to be minimally impacted by an increase in sea levels, given that they have the infrastructure to travel further (larger boats);
- Traditional inhabitant fishers may be highly impacted by this change, as they often do not have the infrastructure and processes to engage in fishing further distances.

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CLIMATE ADAPTATION
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Supply chains and climate change

Commonwealth Trawl Sector

Number 4

Supply chains represent the different components of the food production system from capture to consumption. To date, most climate change research on fisheries has been on the capture stage – the fishers. As climate change has the potential to impact on many components of the supply chain, opportunities for efficiencies and adaption may occur at different points along the supply chain. This project considered a number of Australian fishery and aquaculture sectors, to identify opportunities for increasing resilience to climate change, including development of adaptation options. The project defined supply chains and used them as a basis for identifying critical components and environmental footprints. Investigation of market conditions along with scenario analysis with stakeholders revealed additional options. These adaption options and efficiency suggestions can be implemented by supply chain actors, or by policy and management agencies.

The Commonwealth Trawl Sector (CTS) is one of four sectors in the Southern and Eastern Scalefish and Shark Fishery (SESSF). It covers the area extending southward from Barranjoey Point (NSW), around the coastlines of NSW, Victoria, Tasmania to Cape Jervis in South Australia. The CTS is the largest sector in terms of catch and value and is one of Australia's oldest commercial fishing sectors. There are four principal species caught in the Commonwealth Trawl Sector: Blue Grenadier (*Macruronus novaezelandiae*), Tiger Flathead (*Platycephalus richardsoni*), Pink Ling (*Genypterus blacodes*) and Silver Warehou (*Seriolella punctata*).

Commonwealth Trawl Sector (CTS)

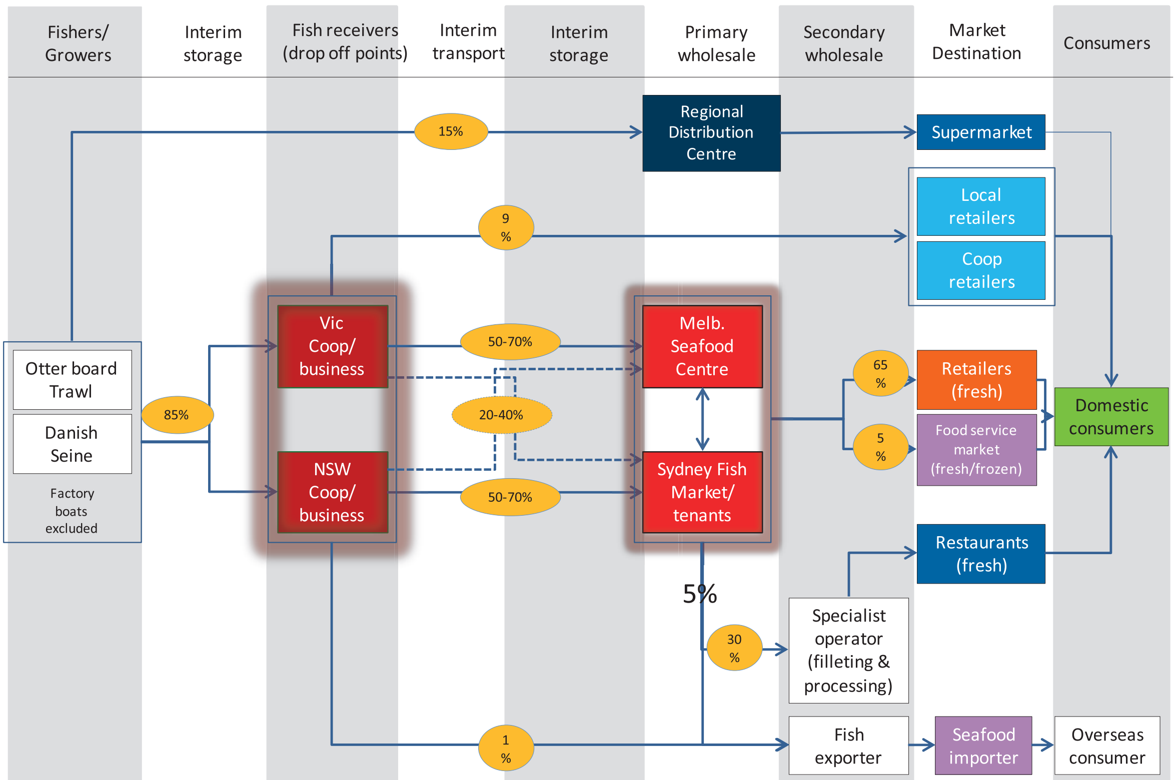

FIGURE 1 **CTS supply chain, showing the relative flow of product with colour coding to highlight critical elements. Individual Supply Chain Index (SCI) scores for each element in the supply chains are coloured when they represent 1% or more of the total score. From highest to lowest scores, the colour coding used is red (>20%)-orange-green-blue-purple. Additional highlights to the red and orange boxes emphasize the critical elements. The supply chain components are based on common templates used for consistency for all fisheries considered in this project.**

Critical elements in the supply chain

The SCI provides one way of identifying critical elements based on large throughput rates and greater connectivity, but doesn't consider all factors such as economic efficiency or risk of being perturbed.

The critical elements identified for the CTS are:

- Victorian and New South Wales co-operative businesses;
- Melbourne and Sydney fish markets;
- Fresh fish retailers.

Environmental footprint for the supply chain

Life cycle assessment (LCA) takes into account the environmental footprint of the supply chain. It includes the environmental consequences of the inputs such as the production of the fishing gear, the production of fuel and transportation.

The main LCA components for CTS are:

- Global warming potential – trawl fishing contributes more to global warming than Danish seine at the capture stage, while the electricity used for ice production, cool rooms, lighting and office administration are the biggest contributors at the processing stage;
- Cumulative energy demand – electricity and transport are the major contributors here after the capture stage;
- Water use – the production of fishing nets, ice and diesel are the major users of water in the capture phase, while the production of ice, handling/cleaning are the major users of water in the processing stage.

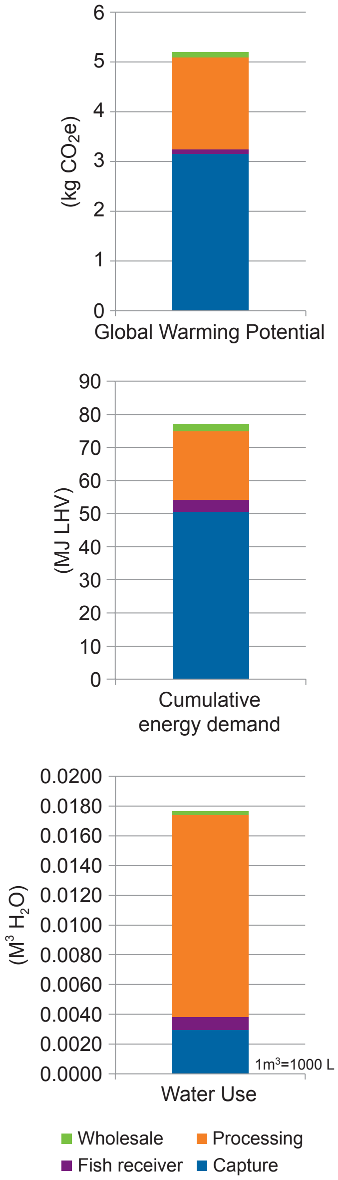

FIGURE 2 **Contribution by category to the life cycle impacts of 1 kg whole fresh fish from the CTS at wholesale.**

Future adaptation options

Two potential future scenarios based on literature reviews, expert opinion and stakeholder interviews and related projects were presented to stakeholders.

Scenario one
Potential supply change

> A gradual change in the distribution of key species to the south as a result of warming eastern Australia waters.

Scenario two
Potential demand change

> Increased supply of similar seafood from international markets, from other areas less affected by climate change, leads to increase competition in the domestic markets.

The adaptation options and stakeholder interviews showed that:

- The supply led nature of this supply chain suggests it may be more vulnerable to climate change than other fisheries looked at;
- Long term increases in efficiency may occur as a result of fleet and logistic movements south, but an increased environmental footprint is expected in the short term in response to changing fish distributions;
- A smaller fleet could in fact result in a higher CPUE as fewer boats will be competing to catch the fish. Should this be the case fishery fuel use will fall and lead to a smaller footprint per kilo of fish caught at the capture phase in the CTS.

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Supply chains and climate change

Sydney Rock Oyster

Number 5

Supply chains represent the different components of the food production system from capture to consumption. To date, most climate change research on fisheries has been on the capture stage – the fishers. As climate change has the potential to impact on many components of the supply chain, opportunities for efficiencies and adaption may occur at different points along the supply chain. This project considered a number of Australian fishery and aquaculture sectors, to identify opportunities for increasing resilience to climate change, including development of adaptation options. The project defined supply chains and used them as a basis for identifying critical components and environmental footprints. Investigation of market conditions along with scenario analysis with stakeholders revealed additional options. These adaption options and efficiency suggestions can be implemented by supply chain actors, or by policy and management agencies.

Sydney rock oysters, *Saccostrea glomerata,* (SRO) are cultivated along the coast of NSW and south-east QLD. The cultivation of SROs has a long tradition in Australia dating back over 120 years. Today, SROs have a predominantly domestic market with less than 1% of export sales. The industry has experienced increased competition from Pacific oyster industry in Tasmania and South Australia over the past decade.

Critical elements in the supply chain

The SCI provides one way of identifying critical elements based on large throughput rates and greater connectivity, but doesn't consider all factors such as economic efficiency or risk of being perturbed.

The Sydney rock oyster supply chain is highly linear at the supply end, with the interim storage and transport identified as key elements. The dominance of these two elements suggests that this supply chain may be particularly vulnerable

Sydney Rock Oyster (SRO)

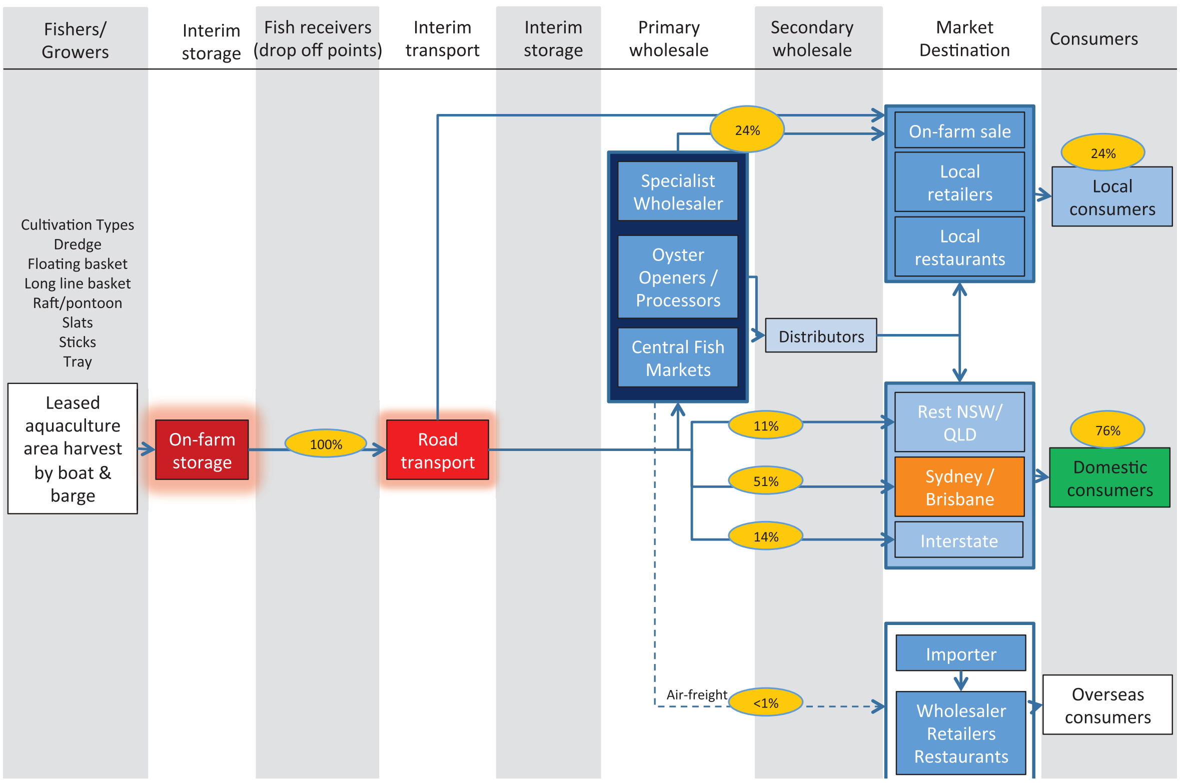

FIGURE 1 **SRO supply chain, showing the relative flow of product with colour coding to highlight critical elements. Individual Supply Chain Index (SCI) scores for each element in the supply chains are coloured when they represent 1% or more of the total score. From highest to lowest scores, the colour coding used is red (>20%)-orange-green-blue-purple. Additional highlights to the red and orange boxes emphasize the critical elements. The supply chain components are based on common templates used for consistency for all fisheries considered in this project.**

to external factors impacting on these key elements, and hence that this chain may not be as resilient as other seafood supply chains.

Market analyses

Market analyses consider the relationships between domestic and international markets, volume of product and price and completion from other producers.

Economic competition between seafood products is of interest for industry stakeholder since an increase in production can affect price formation if products are part of the same market or even substitutes. Schrobback et al (manuscript under review) found that:

- SROs and Pacific oyster (second major commercial species produced in Australia) markets are integrated. This means that over the long run prices in both markets move together but may not necessary be the same;
- The market share of SROs decreased from about 70% in 1989 to 30% in 2011 compared to an increasing share of Pacific oysters;
- SRO prices are adversely affected by increasing Pacific oyster supply but not vice versa, suggesting that both species are not perfect substitutes.

Given the existence of a competing Pacific oyster market, the adaptation of the SRO supply chain to the challenges of changing climatic conditions are important for the industry's future prospects.

Future adaptation options

Two or three potential future scenarios based on literature reviews, expert opinion and stakeholder interviews and related projects were presented to stakeholders.

Scenario one
Potential supply change

> Extreme weather events (e.g. floods occurring in SE Australia) lead to closures of lease due to:

– i) run-off pollution form acid sulphate soils caused by upstream farming activities,

– ii) fresh water flooding which leads to the delusion of saline water,

– iii) disease outbreaks, and

– iv) algal blooms.

Scenario two
Potential demand change

> Consumer demand for oysters slowly decreases due to a perception of contamination of oysters in coastal areas of eastern NSW.

The adaptation options and stakeholder interviews showed that the Sydney rock oyster fishery has been exposed to extreme weather events leading to flooding and the temporary closure of leases as a result. The key concern for members of the industry is the frequency to which such events would occur. Businesses would not be able to cope if supply was interrupted frequently and customer trust would be eroded over time, limiting the ability of fishers to re-establish connections once supply resumes

Possible adaption options include the investment in research addressing disease resistance, to manage the impacts of pollution and minimise impact on supply. Stakeholders also consider a shift from intertidal to sub-tidal production, to build resilience from flooding as well as manage impacts of extreme temperatures currently experienced in intertidal production. This adaptation however, is seen as quite costly and is considered a transformation for the industry which could result to some growers leaving rather than making the change as areas for sub-tidal production are limited. The engagement in a publicity campaign to inform consumers about the effects of different types of environmental conditions to human health is seen as a way to increase consumer awareness.

Reference

Schrobback P, Pascoe S and Coglan L (manuscript under review) Impacts of introduced aquaculture species on markets for native marine aquaculture products: The case of edible oysters in Australia. Aquaculture Economics & Management (submitted May 2013).

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This project was funded by the Australian Government.

Supply chains and climate change

Aquaculture prawn

Number 6

Supply chains represent the different components of the food production system from capture to consumption. To date, most climate change research on fisheries has been on the capture stage – the fishers. As climate change has the potential to impact on many components of the supply chain, opportunities for efficiencies and adaption may occur at different points along the supply chain. This project considered a number of Australian fishery and aquaculture sectors, to identify opportunities for increasing resilience to climate change, including development of adaptation options. The project defined supply chains and used them as a basis for identifying critical components and environmental footprints. Investigation of market conditions along with scenario analysis with stakeholders revealed additional options. These adaption options and efficiency suggestions can be implemented by supply chain actors, or by policy and management agencies.

The Australian prawn industry is primarily located in North Queensland between Ayr and Port Douglas. Other areas in include the Gold Coast, Sunshine coast, Bundaberg, Mackay (QLD), Ballina and Coffs Harbour (NSW). The main species farmed in Australia is the black tiger prawns (*Penaeus monodon*). Other species farmed include the highly valued Kuruma prawns (*P. japonicus*) and Banana prawns (*P. merguiensis*). Aquaculture prawns accounted for six percent of the total value of Australian aquaculture production in 2010-2011 (Skirtun *et al*).

Critical elements in the supply chain

The SCI provides one way of identifying critical elements based on large throughput rates and greater connectivity, but doesn't consider all factors such as economic efficiency or risk of being perturbed.

Aquaculture prawn

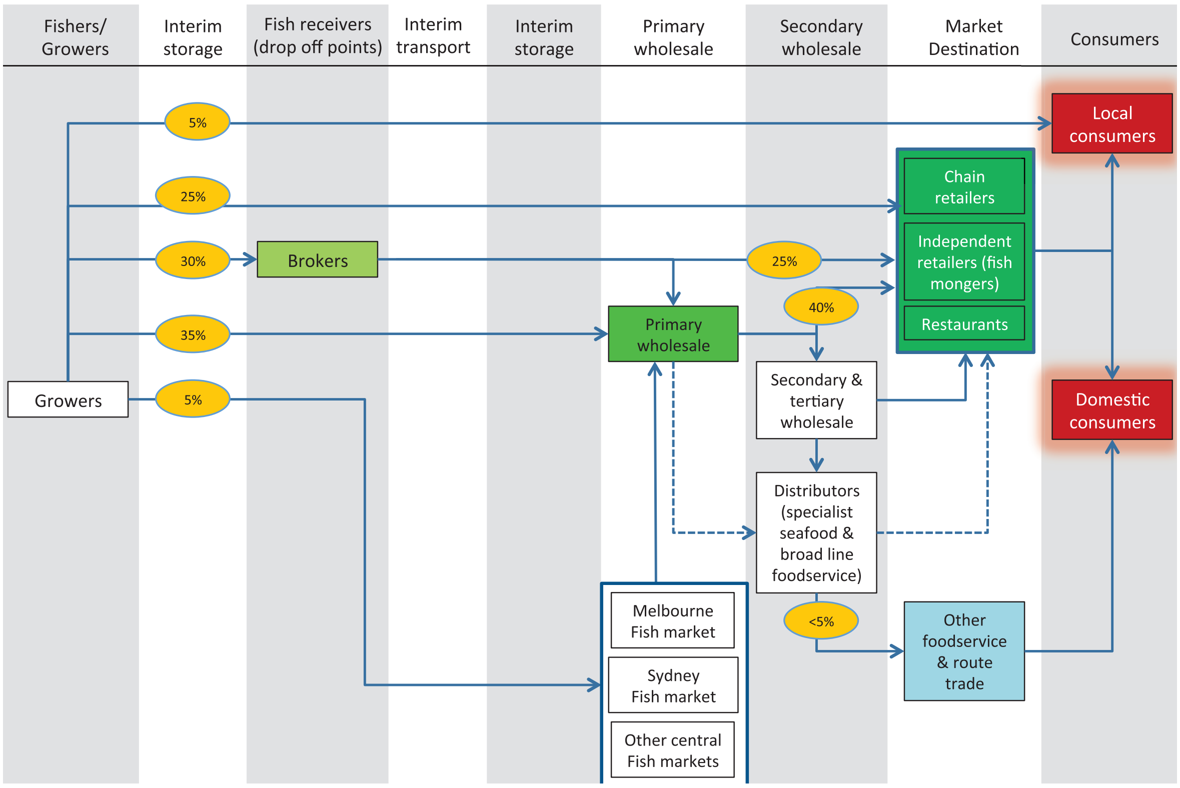

FIGURE 1 **Aquaculture prawn supply chain, showing the relative flow of product with colour coding to highlight critical elements. Individual Supply Chain Index (SCI) scores for each element in the supply chains are coloured when they represent 1% or more of the total score. From highest to lowest scores, the colour coding used is red (>20%)-orange-green-blue-purple. Additional highlights to the red and orange boxes emphasize the critical elements. The supply chain components are based on common templates used for consistency for all fisheries considered in this project.**

The Australian aquaculture prawn supply chain differed from the other fisheries studied in that there was a single dominant key element, namely the domestic consumers. Hence attempts to increase the diversification (if not already the case) of the domestic consumer market will improve the stability of this supply chain.

Market analyses

Market analyses consider the relationships between domestic and international markets, volume of product and price and completion from other producers.

The main market analyses results for aquaculture prawns show:

- A co-integration between Australian wild and farmed prawns and prawn import prices. Analysis suggests that while imports will depress the price received by Australian prawns it will not be necessarily the other way around;
- Imported prawns are of lower value than Australian prawns;
- Changes in food expenditure per capita have the biggest effect on Australian prawn prices;
- The increase in prawn imports was found to potentially cause a bigger reduction in Australian prawn prices than if their own quantities were to increase in the market;
- The increase in exchange rate has pushed higher valued wild prawns that were previously exported into the domestic market.

Future adaptation options

Three potential future scenarios based on literature reviews, expert opinion, stakeholder interviews and related projects were presented to stakeholders.

Scenario one
Potential supply change

> Increased flooding regimes with a net increase of suitable aquaculture habitat.

> Increase in extreme events (cyclone, flooding, heat and frequency and/or nature/type of diseases) affecting ponds and prawns.

Scenario two
Potential demand change

> Increase competition as a result of cheaper imports & higher supply from wild-caught banana prawns.

The adaptation options and stakeholder interviews showed that:

- Sea level rise along the Queensland coast is expected to result to some areas of agricultural land becoming marginalised, especially where sugar cane is grown. This is seen as an opportunity by some to potentially expand aquaculture in such areas;
- An increase in extreme events affecting areas where prawns are farmed and distributed is seen by some stakeholders as a concern. The primary concerns are a disruption in power supply, affecting pond operation and on-farm cold storage, as well as a disruption of transport routes, which can impact on the inbound flow of farm supplies (feed, fuel) and outbound flow of product to markets.

Reference

Skirtun M, Sahlqvist P, Curtotti R and Hobsbawn P (2012) ABARES 2012, Australian fisheries statistics 2011, Canberra, December. CC BY 3.0.

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