ECONOMIC ANALYSES OF AUSTRALIA'S SYDNEY ROCK OYSTER INDUSTRY

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ABSTRACT

This thesis focuses on one of Australia's oldest farming industries, the Sydney rock oyster industry. This industry has been facing a range of environmental challenges over the past decades which continue to affect its productive capacity today. However, there is limited information available about economic aspects that may affect the viability of this industry. The purpose of the research presented in this thesis is to enhance the understanding of the economic status quo and the potential future economic viability of this industry.

This thesis provides four studies that assess the economic status quo of the Sydney rock oyster industry. First, a socio-economic profile of the industry is developed based on findings from a farm survey. This profile reveals the presence of demographic and structural issues within the industry. The second study investigates price formation dynamics in Australia's oyster market and shows that Sydney rock oyster prices have been negatively affected by an emerging Pacific oyster industry over the past decade. An analysis of production efficiency and capacity utilisation was undertaken in a case study for Moreton Bay, the industry's northern most production area. Results suggest that demographic characteristics as well as environmental factors affect oyster production in this area. The last study focuses on modelling the impact of climate change and market dynamics on the revenue of the Sydney rock oyster industry. The findings from this study reveal that the effect of projected climate change on the industry's revenue may only be moderate overall but production areas will likely be affected on differing levels. Furthermore, market dynamics will likely have a larger impact on the future economic sustainability of the industry than direct effects from climate change.

The implications for the management of the industry from the findings of the four studies are discussed in this thesis and recommendations for industry development strategies are proposed.

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LIST OF ABBREVIATIONS

ABARES	:	Australian Bureau of Agricultural and Resource Economics and Sciences
ABARE	:	Australian Bureau of Agricultural and Resource Economics
ABS	:	Australian Bureau of Statistics
ADF	:	Augmented Dickey Fuller
AE	:	Allocative efficiency
ARDL	:	Autoregressive distributed lag
CRS	:	Constant returns of scale
CSIRO	:	Commonwealth Scientific and Industrial Research Organisation
CU	:	Capacity utilisation
DEA	:	Data envelopment analysis
DMU	:	Decision making unit
FTE	:	Full-time equivalent
I(0)	:	No cointegration
I(1)	:	Cointegration
LOP	:	Law of One Price
NSW	:	New South Wales
NSW DPI	:	New South Wales Department of Primary Industries
OISAS	:	Oyster industry sustainable aquaculture strategy
OLS	:	Ordinary Least Squares
POMS	:	Pacific oyster mortality syndrome
PPT	:	Parts per thousand
QLD	:	Queensland
QLD DAFF	:	Queensland Department of Agriculture Fisheries and Forestry
QLD DPI&F	:	Queensland Department of Primary Industries and Forestry
QUT	:	Queensland University of Technology
RE	:	Revenue efficiency
SA	:	South Australia
SE	:	Scale efficiency
SIC	:	Schwarz Information Criterion
SRO	:	Sydney rock oyster
SUR	:	Seemingly unrelated regression
TAS	:	Tasmania
TE	:	Technical efficiency
UCU	:	Unbiased capacity utilisation
VAR	:	Vector autoregressive
VRS	:	Variable returns to scale
WA	:	Western Australia

STATEMENT OF ORIGINAL AUTHORSHIP

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

QUT Verified Signature

Signature:

Date: 16th April 2015

LIST OF PUBLICATIONS, PRESENTATIONS, INTERVIEW AND AWARD

Publications

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Schrobback, P., Pascoe, S., & Coglan, L. (2014). Impacts of introduced aquaculture species on markets for native marine aquaculture products: The case of edible oysters in Australia, *Aquaculture Economics and Management*, *18*(3), 248-272. (CHAPTER 5)

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Oral presentations

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Schrobback, P., Pascoe, S., & Coglan, L. (2014). A socio-economic profile of Australia's Sydney rock oyster industry, 58th Australian Agricultural and Resource Economic Society Conference, 4 – 7 February 2014, Port Macquarie.

Schrobback, P., Pascoe, S., & Coglan, L. (2012). Market integration and demand analysis of the Australian edible oyster market, 56th Australian Agricultural and Resource Economic Society Conference, 7 – 10 February 2012, Fremantle.

Interview

ABC (Rural) Radio, Oyster growers older than average farmers, Monday 10 February 2014, 5:22pm.

Award

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Chapter 1: Introduction

1.1 BACKGROUND

Fisheries economics and marine resource economics are interdisciplinary fields of research which analyse the links and interdependencies of processes in natural marine ecosystems and human society that govern the production, distribution and consumption of marine goods and services in an exchange economy.

Fisheries economics utilises economic theory and models to inform appropriate management of the fish stocks for the benefit of the society, while marine resource economics takes a broader view at the full set of ocean-based resources – both commercial (*e.g.*, fish stocks) and non-commercial (*e.g.*, biodiversity).

The notion of the tragedy of the commons is well understood in fisheries (Hardin, 1968): Fishers are allowed to compete for a common pooled resource (fish stock) to maximise an individual profit objective function, the resource may be prone to overfishing (*i.e.*, the biomass will be less than the optimal biological sustainable level), in some circumstances to the point of extinction (C. W. Clark, 1973). Given this notion, fisheries in developed countries are commonly regulated industries that aim to obtain the greatest benefits to society from the use of society's resources. Fisheries economics seeks to inform fishery management how to achieve, both, a sustainable resource and positive economic returns for both the fishers and the society, who ultimately own the resources.

Aquaculture economics is a subset of fisheries economics. Whilst not necessarily targeting a common fish stock, aquaculture production still utilises common property resources (*e.g.*, water ways and in many cases fish stocks derived from natural sources), and can potentially create environmental externalities (*e.g.*, effects of invasive species on local ecosystems). Therefore, their activities need to be subject to regulation to ensure that activities adhere or meet broader societal interests. In this regard, economic research is central in providing the aquaculture industry and policy makers with baseline economic information to guide the sustainable development of the industry. This includes, but is not limited to, production analysis (examination of production functions, technical efficiency among others), market studies (demand function analysis) and bio-economic modelling. The latter seeks to look at the interactions within the various components of the whole aquaculture industry/system (*e.g.* ranging from biophysical production conditions to economic revenue) and can be used to analyse how different policies will effect interactions and the resultant effect on the economic viability of the industry.

The focus of the research presented in this thesis is on the edible oyster industry in Australia, particularly, the Sydney rock oyster (SRO), *(Saccostrea glomerata)* industry, an important part of the Australian aquaculture sector.

1.2 SIGNIFICANCE OF RESEARCH

Australia's edible oyster industry is comprised by two main commercial oyster species, the native SRO and the non-native Pacific oyster (*Crassostrea gigas*). The habitat of the naturally occurring native SRO is almost exclusively confined to coastal waters of south-east Queensland (QLD) and New South Wales (NSW). Moreover, most oyster producing estuaries for this species are located in a relatively long distance (up to 500 kilometres) from the major cities of Brisbane (QLD) and Sydney (NSW). White (2001) estimated that the NSW oyster industry provides employment for about 1,600 people and that every direct job in the industry creates up to three indirect jobs. Therefore, the oyster industry in these States is an important contributor to employment and income generation in small coastal communities.

The SRO industry is regulated in terms of where the oyster farms may be placed, how oyster production may be undertaken and also which species of oysters may be farmed. There is also ongoing environmental monitoring of water quality affecting or affected by oyster production.

The SRO industry experienced a vast expansion of its production volume during the first part of the 20th century and production output peaked in the late 1970s. Until the early 1990s this industry was the leading aquaculture industry in Australia (ABARE, 1991). Since then, the production volume has decreased significantly from about 9,973 metric tons annually in the mid-1970s to approximately 4,500 metric tons in 2012 (ABARES, 2013; Pease & Grinberg, 1995). Today, the SRO industry only contributes a small share to the nation's total aquaculture production, which is dominated by salmonids, tuna, prawns, and pearl oyster production (ABARES, 2013).

The major reasons that contributed to the decrease in production volume of the industry appear to be of environmental nature. Since the late 1970s the industry has been challenged continuously with the occurrence of the QX disease, which significantly affected its oyster production capacity. Other environmental issues that have affected oyster production in NSW and Queensland in the past decade include a decline in estuary water quality due to extended catchment and coastal development as well as increased run-off from acid sulphate soils in a number of coastal flood plains (O'Connor & Dove, 2009). Furthermore, intense rain periods resulting in prolonged freshwater events have severely affected oyster production in recent years (*e.g.*, flood in Brisbane River in 2011 and associated decline in water quality negatively affected oyster growing areas in Moreton Bay). An additional environmental concern for the SRO industry provides the ecological competition of non-native invasive Pacific oysters. Pacific oysters were deliberately introduced to Tasmania (TAS) and South Australia (SA) in 1950s and 1960s (Mitchell *et al.*, 2000; PIRSA, 2003) and have spread to SRO production areas in NSW and Queensland. This invasive species can outcompete and displace the SRO from its habitat and, thus, compromise production of the native species. The control of Pacific oysters and risk management activities continue to be necessary to avoid further infestation of Pacific oysters in NSW and Queensland.

Further environmental stress from climate change may add to the industry’s challenges in the future (Parker *et al.*, 2009, 2010, 2011; Parker *et al.*, 2012). Some areas in the oyster production process that need adaptations under climate change scenarios have been identified by industry members (Leith & Haward, 2010). However, strategies and potential implications of climate change have gained very limited attention in current industry development plans (NSW DPI, 2014b; QLD DPI&F, 2008a). Furthermore, quantification of the potential impact of climate change on the economic sustainability of the industry has not yet been undertaken. This may explain the lack of adaption planning in present industry management strategies.

The sustainability of the SRO industry does not only seem to be affected by environmental challenges but also by economic factors, such as seafood and oyster market dynamics. For example, the SRO industry has experienced growing competition from an increasing production of Pacific oysters in Tasmania and South Australia over the past 15 years. The Pacific oyster is growing faster than the SRO and therefore is a commercially attractive oyster species. In the early 2000s, the allocation of more productive growing sites by State authorities to oyster farmers, particularly in South Australia, resulted in considerable increase in Pacific oyster production and market dispersion (Trudy McGowan, South Australian Oyster Growers Association, personal communication, 5 December 2011). At the same time the market prices of SRO started to decrease (ABARES, 2011). It is believed that this effect has led to a decrease in the profitability of oyster farming in Queensland and NSW. Yet, an economic analysis to verify this effect has not been undertaken to this stage.

Furthermore, there is only limited information available about the demographic characteristics of oyster growers and their technical capability to produce oysters which could affect the sustainability of the industry. These aspects can have an effect on the farmer's ability to adopt innovative production and marketing strategies and their overall productivity and can eventually influence their capability to generate positive return from aquaculture activities.

Additionally, the lack of general economic information about this industry limits the capability of the industry management and policy to make informed decisions about the future development of this industry. Without an enhanced understanding of the combined environmental and economic issues the industry bears the risk of losing its economic viability in the medium to long-run.

1.3 OBJECTIVE AND RESEARCH QUESTIONS

The objective of the research in this dissertation was to enhance the understanding of the economic status quo and potential future economic viability of the SRO industry. In order to achieve this objective the following research questions were addressed:

- What is the current socio-economic profile of the industry? What is its role in the industry's economic performance?

- How does change in production affect oyster prices? And how has increased Pacific oyster production affected the prices of SROs?
- What is the level of production efficiency in the industry? What are the main drivers of efficiency in the industry: Producer characteristics or external factors (*e.g.*, environmental factors)?
- How is climate change likely to affect the industry in the medium term? Who may be the winners and who may be the losers?
- What are the key focal areas that policy and management should consider in order to support a sustainable future development of the SRO industry?

More detailed information about the objective and how these research questions translate into research aims will be outlined in Chapter 3.

Knowledge about these economic aspects is essential to understand drivers of the industry's economic performance. Furthermore, an investigation of the potential impact of climate change on the economic sustainability of the industry is important for its adaption and future development strategies. Should all these economic aspects not be understood or considered, policy interventions could result in governance failure and lead to unintended externalities, such as the loss of potential resource rent from use of society's resources, social issues in coastal communities and ecological tragedies of common goods. Last but not least, the loss of this traditional industry in the most extreme case, would also mean a loss of considerable existing cultural and heritage value to the Australian society.

Chapter 2: Industry background

2.1 INTRODUCTION

The SRO industry is one of Australia's oldest farming industries. This industry is unique as it is based on an oyster species that is only found in Australia. In order to understand the economic status quo of this industry, information about historic and recent events is important as it may explain the origins of current developments within the industry. The purpose of this chapter is to review the available literature about the SRO industry and to provide a summary of gaps in the field of economic research that relate to this primary industry.

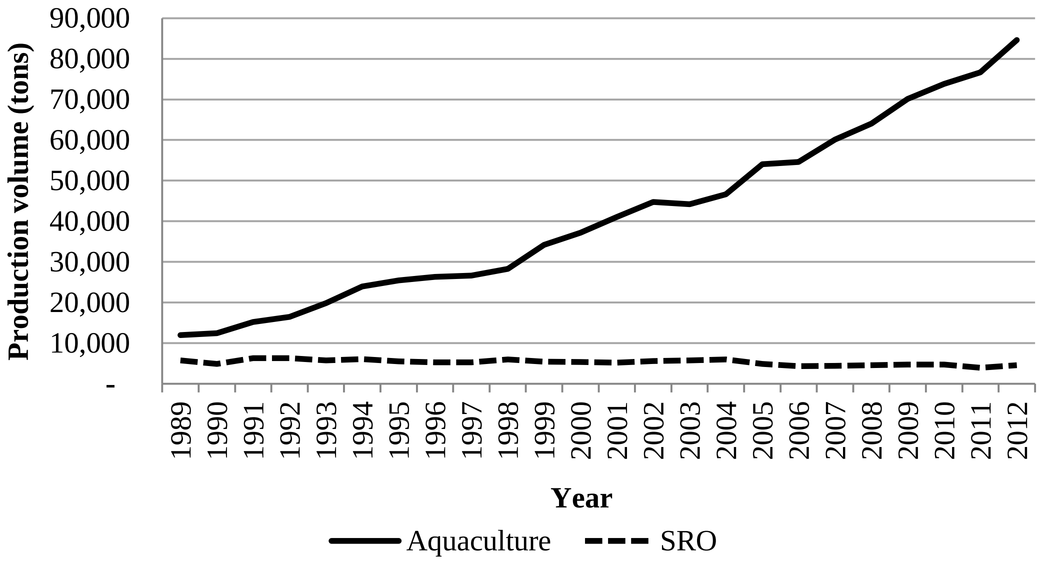
This chapter offers a brief overview about the aquaculture sector in Australia and the role of the SRO industry within this sector. Following that, a short summary about Australia's edible oyster industries and key features of the SRO as an edible shellfish is given. A detailed overview about industry's history, the current challenges, industry management, market settings, and innovation amongst other topics, provides an outline about past events and the status quo of the industry. Finally, a summary of findings about the available literature and an identification of research gaps are given.

2.2 AQUACULTURE IN AUSTRALIA

Aquaculture comprises the commercial farming of marine or freshwater finfish (*e.g.,* salmonids and tuna), crustaceans (*e.g.,* prawns), molluscs (*e.g.,* mussels and oysters) and aquatic plants and animals (*e.g.,* sea cucumber) (Wilson *et al.*, 2010). In contrast to capture fisheries, aquaculture involves cultivating animal populations under controlled conditions over all phases of a life cycle (Bardach, 1997). It also includes preventing their escape, protecting stocks against diseases and predators, and attending to the quality of water (Naylor *et al.*, 2000). In Australia marine- (onshore and offshore), freshwater- and pond-based aquaculture production are common (Love *et al.*, 2004).

Australia's aquaculture production volume has increased significantly since the late 1980s (see Figure 2.1). This increase was due to the development of existing aquaculture industries, for example the Pacific oyster industry in Tasmania, and the establishment of new industries, such as the southern bluefin tuna and the Pacific oyster industry in South Australia and the Atlantic salmon industry in Tasmania. The total volume of aquaculture production in 2012 was about 84,600 tons, which accounts for 36 per cent of total Australian fisheries production (ABARES, 2013). The gross value of aquaculture production was 1.1 billion Australian Dollars which equates to 46 per cent of the gross value of Australian fisheries production (ABARES, 2013).

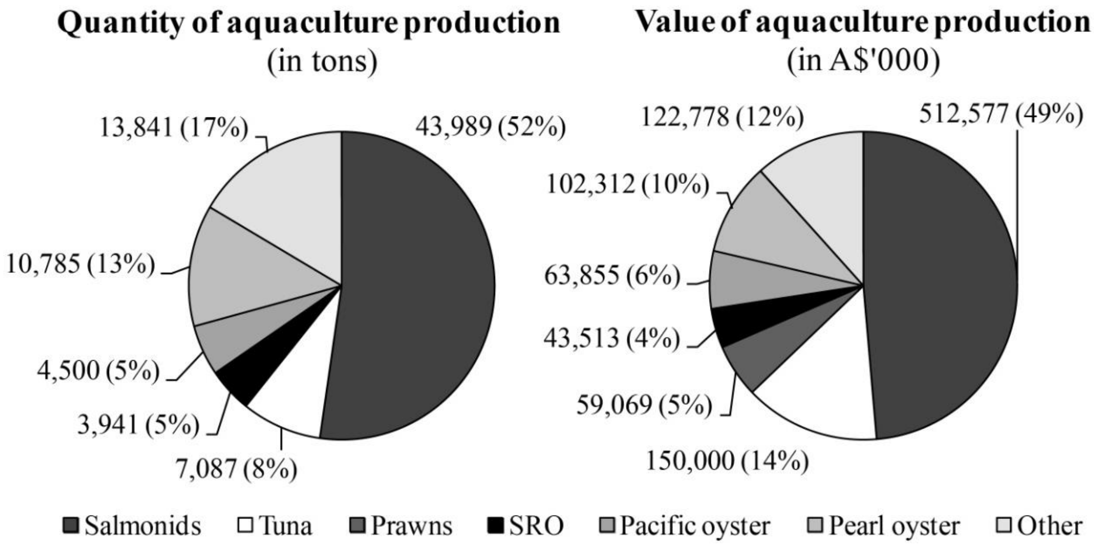
Figure 2.1: Development of Australia's aquaculture production volume over time



Source: ABARE (1991), ABARES (2013).

The major fish species currently farmed in Australia include salmonids, southern bluefin tuna, prawn, pearl and edible oysters, which account for 88 per cent of the total aquaculture production value (see Figure 2.2) (ABARES, 2013).

Figure 2.2: Quantity and value of aquaculture production in Australia



Notes: Production quantities of pearl oysters are not available due to the high protection of the industry; Source: ABARES (2013).

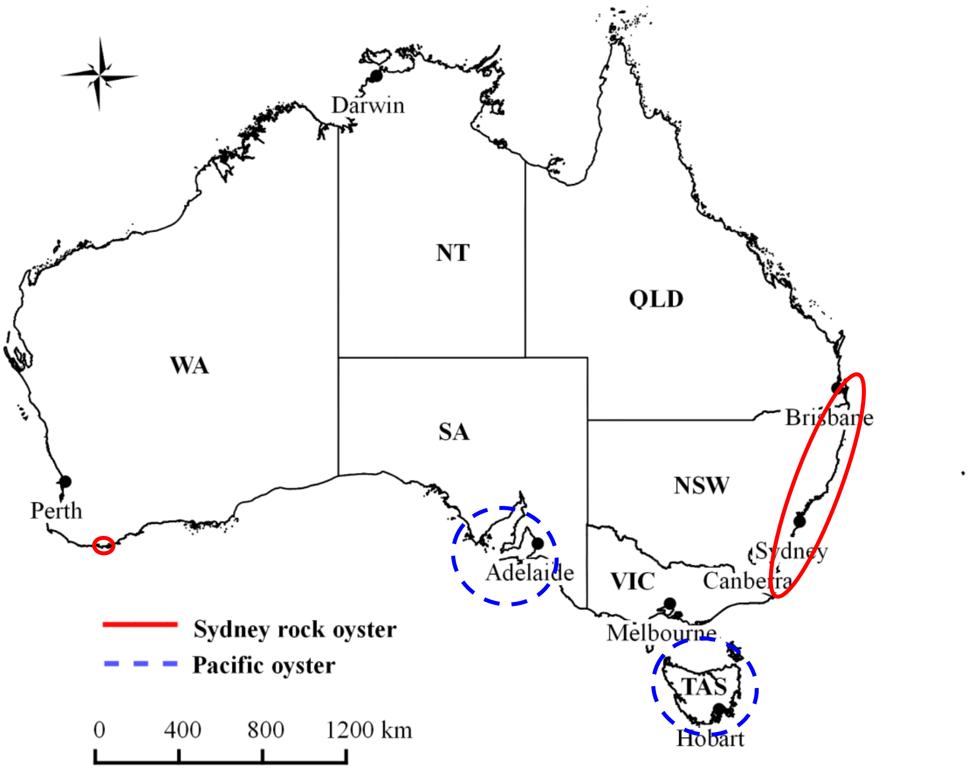
The SRO industry was the leading aquaculture industry in Australia until the early 1990s when it contributed about half of the Australia's aquaculture total production volume (ABARE, 1991) (see Figure 2.1). Compared to the rising trend in Australia's total aquaculture production volume during the period 1989-2012 the production quantity of the SRO industry slightly decreased during the same time (Figure 2.1). Today, the current share of the SRO industry in total aquaculture production volume and gross value is relatively small with only 5 per cent and 4 per cent, respectively (Figure 2.2).

2.3 EDIBLE OYSTERS PRODUCTION IN AUSTRALIA

Edible oysters occur naturally on rocky shores, in estuaries, bays and tidal waterways (hereafter estuaries) along the Australian coast. The native Sydney rock oyster (*Saccostrea glomerata*) is cultured in NSW, south-east Queensland and on one lease in Albany, Western Australia (WA) (see Figure 2.3). The SRO industry is one segment of Australia's edible commercial oyster industry. The second major segment is comprised of the Pacific oyster (*Crassostrea gigas*) industry. The Pacific oyster is native to Japan and was deliberately introduced to Tasmania in the 1950s (Mitchell *et al.*, 2000) and to South Australia in the late 1960s (PIRSA, 2003).

Other native oyster species farmed in Australia include the native flat oysters (*Ostrea angasi*) (also called Angasi oyster which native in the southern States of Australia), the northern black lip oyster (*Striostrea mytiloides*) and the milky oyster (*Saccostrea cucculata*) (both native to Queensland) (ABARE, 2003a). However, production of these species is considerably smaller compared to the two major cultivated species and are either partially or not reported in State and national aquaculture production statistics (ABARE, 2003a; ABARES, 2013).

Figure 2.3: Spatial distribution of major commercial edible oyster farming areas in Australia



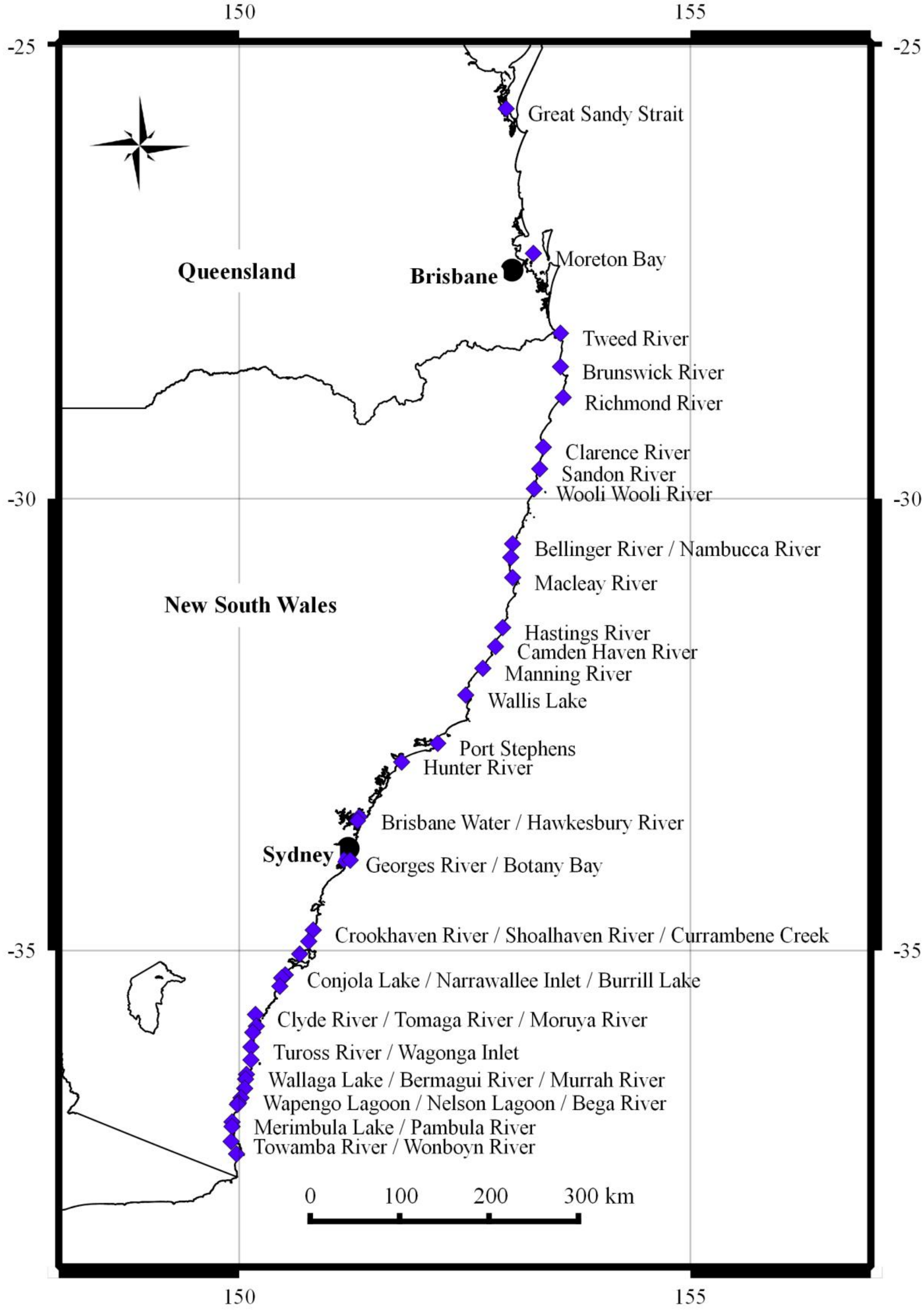
2.4 THE SYDNEY ROCK OYSTER

The SRO is classified as bivalve, meaning two shells, and belongs to the group of animals with shells, called molluscs. The oyster shell is comprised of calcium carbonate and protects the inner organs or oyster meat. A detailed description of the anatomic characteristics of SROs is provided by Smith and Reddy (2012).

Today, this native Australian oyster species is cultivated in estuaries between Wonboyn River in southern NSW and Moreton Bay in Queensland (see Figure 2.4).

Factors that influence the suitably of an area for oyster cultivation and growth include water temperature; organic particulate matter concentration; phytoplankton biomass normally estimated by chlorophyll-a concentrations; nutrient inputs; water flow and depth, salinity level (Dove & O'Connor, 2007; Green & Barnes, 2010b; Rubio Zuazo, 2008).

Figure 2.4: Map of SRO producing estuaries



SROs require two to two a half years to reach a very small (cocktail) or small (bottle) marketable size (NSW DPI, 2011). Larger oyster sizes (also called grades) are called bistro, plate, standard and large and vary in growing time, length and meat weight. The most commonly produced grades are bottle (whole weight: 35 gram, shell length: 66 mm), bistro (whole weight: 45 gram, shell length: 73 mm) and plate (whole weight: 77 gram, shell length: 73 mm) (NSW DPI, 2005). Marketability attributes of SROs include oyster health, freshness, shell size, shape and cleanness, and meat weight.

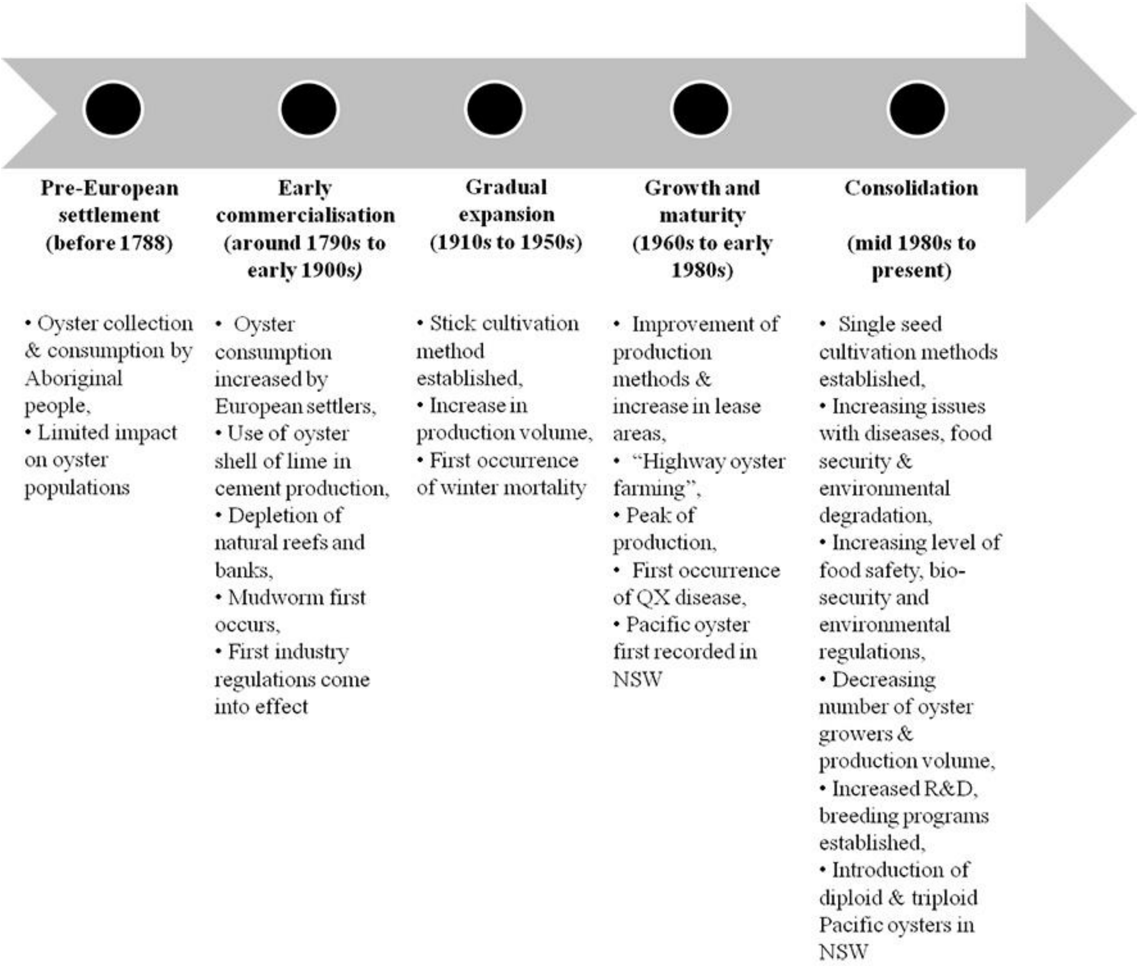
The SRO is a gourmet shellfish and is best eaten fresh on the half-shell. Live SROs are optimally stored at 8-10 °C, at this temperature they can be kept alive in good condition for 2 weeks (NSW DPI, 2005). Opened oysters, should be refrigerated at 4 °C and have a typical shell life of 7-10 days (NSW DPI, 2005). The nutritional value of oysters is characterised by a high content of iron, zinc, proteins and vitamins (Jones, 1926; Levine *et al.*, 1931). Similar to other fish, oysters are low in saturated fats and carbohydrates (Jones, 1926).

2.5 REVIEW OF THE SYDNEY ROCK OYSTER INDUSTRY

Knowledge about historic events within an industry is important as they may explain the present state and trends of the industry. The history of the SRO industry has previously been reviewed in differing detail and scope by Smith (1985), Nell (2001), Lergessner (2006), Ogburn *et al.* (2007), O'Connor and Dove (2009), Ogburn (2011), Clarke (2013) and references cited therein. The review of the industry has been focused on the more recent development, which had not been covered adequately in the previous reviews. It is also important to highlight that the NSW part of the industry received most attention in the existing literature and has therefore also been focal point of this review.

The development of the SRO industry can be divided into 5 phases that are: Pre-European settlement, early commercialisation, gradual expansion, growth and maturity and consolidation/status quo (see Figure 2.5). Each development phase will be described in the following sections.

Figure 2.5: Development stages of the Sydney rock oyster industry



2.5.1 Pre-European settlement (before 1788[1])

Native oysters grew predominantly on large intertidal and sub-tidal oyster banks and reefs along the east coast of Australia long before the European settlement (Lergessner, 2006; G. Smith, 1985). Archaeological evidence in the form of shell midden confirms that Aboriginals in coastal communities continuously collected and consumed native oysters in the northern estuaries of NSW date back as approximately 1720 before present (Bailey, 1975). It is likely that Aboriginal exploitation of this resource goes back further and that evidence for this has been destroyed by rising sea levels (Attenbrow, 2002). Shell deposits at archaeological sites also showed that the Aboriginal people used oyster shells as fish-hooks, hand-held implements to repair spears and for other cutting and piercing tasks (Attenbrow, 2002). The impact of the Aboriginal people on oyster populations during pre-European settlement can most likely be rated as relatively benign, considering the

[1] The year 1788 marked the founding of the first British colony in Australia.

low human population density (Attenbrow, 2002; Bailey, 1975). It has also been suggested that Aboriginal communities placed shell material in the estuary prior to the oyster spawning period, to restore oyster beds by providing substrate for catching new oyster stock (Ogburn *et al.*, 2007).

2.5.2 Early commercialisation (around 1790s - early 1900s)

Large scale gathering of SROs began in the late 1700s north of Sydney soon after the European settlement in NSW (G. Smith, 1985). During these early times, oysters were found in abundance at about four meters below the water mark (dredge oysters) or in beds/banks occurring in the intertidal zone between high and low water marks (bank oysters) (G. Smith, 1985). Dredge oysters were collected by means of a dredging basket operated from a boat (G. Smith, 1981, 1985). Dredge oysters were claimed to grow faster, taste better and sold for higher prices (G. Smith, 1981, 1985). Harvesting bank oysters was more simple since it involved exploitation of oysters occurring naturally attached to stones and dead oyster shells (G. Smith, 1981). These bank oysters were handpicked, either off the ground or off the oyster reefs (G. Smith, 1985). By the 1860s oysters were not only used for consumption but also as a source for lime in cement production (Lergessner, 2006; G. Smith, 1981). To produce lime, live oysters (flesh and shell) were piled in heaps or in lime-kilns and burned to lime, which was used to make mortar for the construction of buildings (G. Smith, 1985).

A rapidly increasing population of European settlers in NSW soon resulted in the overexploitation of the intertidal and sub-tidal reefs and banks (G. Smith, 1985). Due to the serious depletion of wild oyster beds, particularly between 1850 and 1870, oyster spat for restocking the beds was imported from New Zealand, where the same species naturally occurred (G. Smith, 1985). Queensland also provided spat (oyster larvae) to the NSW oyster industry at that time (G. Smith, 1985). The most productive spat and adult oyster producing estuary in Queensland at the time was Moreton Bay at the mouth of the Brisbane River (G. Smith, 1981, 1985).

Concerns about the overexploitation of natural oyster beds during the 1850s-70s led to government regulations being implemented in Queensland and NSW aiming to limit the exploitation of natural oyster beds, *e.g.*, *Oyster Act 1863* and the more comprehensive *Oyster Act 1874* in Queensland; and *Act to regulate Oyster Fisheries and to encourage the formation of Oyster Beds 1868* in NSW (Lergessner, 2006; NSW Royal Commission on Oyster Culture, 1877; Ogburn, 2011; G. Smith, 1981, 1985). For example, these first regulations prohibited the use of oysters for lime production and a licensing system for the oyster fishery was introduced (G. Smith, 1985).

A Royal Commission was appointed in NSW in 1876 to inquire into the best mode of cultivating oysters, of utilising, improving and maintaining natural oyster beds of the NSW and to consolidate and amend the existing laws regulating the oyster fisheries (NSW Royal Commission on Oyster Culture, 1877). The Royal Commission found that the oyster industry in NSW was equal in importance to that of any other commodity industries and that it was necessary to secure the spat (NSW Royal Commission on Oyster Culture, 1877). The findings of the Royal Commission resulted in the *Fisheries Act 1881* which, for example, allowed the appointment of commissioners to overview the oyster fishery activities in NSW (NSW Government, 2014b).

Organised cultivation of oysters for human consumption began at around this time with the setting out of sticks, stones and shells to catch and grow oysters in the intertidal zone to supplement those occurring naturally on the remaining wild oyster beds (Roughley, 1922; G. Smith, 1985).

At around 1882 oyster stocks in the Hunter River, north of Sydney were reported to be affected by a parasitic worm from the polychaete family spionidae (*e.g., Polydora websteri, Polydora ciliata),* which was thereafter commonly called mudworm. Mudworm caused mass mortality of oyster stocks below the mid-tidal level (Nell, 2007; Read, 2010). The sudden appearance, rapid and dramatic impact of mudworm led to a decrease in NSW's production volume from about 15,000 bags (approximately 938 metric tons) in 1886 to approximately 5,000 bags (approximately 313 metric tons) in 1891 (Ogburn *et al.*, 2007). The occurrence of the mudworm disease was later linked to the translocation of oysters from New Zealand to NSW (Ogburn *et al.,* 2007). Translocation of oysters was frequent during the 1870s to replenish oyster populations in NSW estuaries and to sustain the supply of oysters for a growing demand in Australia (Ogburn *et al.*, 2007). However, recent research suggests that this assumption is likely to be incorrect since earliest reports about the mudworm infestation in New Zealand only date from the early 1970s, whereas mudworm had already become widespread along eastern Australian coasts a century earlier (Read, 2010). It could be speculated that the increase in commercial use of SROs including the spat exchange between various production areas may have been a factor in the widespread occurrence of mudworms.

The average value of a bag of oysters (which equals approximately 62.5 kilogram) sold at auctions in 1876 varied between 3 shillings to 20 shillings depending on quality, size and origin (NSW Royal Commission on Oyster Culture, 1877). The total size of the leased area in NSW at that time is not conveyed in previous sources. By the early 1880s the oyster production for human consumption in NSW reached about 7,000 bags (approximately 438 metric tons) of oysters and had increased to over 20,000 bags (about 1,250 metric tons) at the end of the century after the first mudworm crisis was over (Ogburn *et al.*, 2007).

In Queensland, the export of oysters to lucrative southern markets such as Melbourne, Sydney and also to Perth was seen as main reason for exploited oyster stocks. However, a ban to export oysters or a tax on exported oysters could not be introduced due to concerns that too many workers would lose employment as a consequence (G. Smith, 1985). The *1886 Oyster Act (Queensland)* introduced a minimum legal size of oysters (5 centimetres in length) for market sale which was enforced by regular inspections and fines (G. Smith, 1985). This was expected to slow the exploitation of oyster stocks which was caused by the supply of oysters to serve the export demand (G. Smith, 1985). However, this policy proved to be unsuccessful in restricting oyster exports to NSW and Victoria. While exports from Queensland in 1870 amounted to about 4,500 bags (about 281 metric tons), it increased by 1887 to about 7,200 bags (approximately 450 metric tons) and to approximately 21,000 bags (about 1,313 metric tons) in 1891. A total of about 2,751 hectares were allocated to the oyster industry by 1886 in Queensland (G. Smith, 1981). Oyster production in Queensland (Moreton Bay and Sandy Strait areas only) peaked in 1891 (Lergessner, 2006; G. Smith, 1981).

In summary, the phase of early commercialisation of the SRO industry was marked by an increasing demand for oysters from European settlers for consumption and the use of live oysters (shell and flesh) in cement production. The resulting overexploitation led to the depletion of natural oyster reefs and banks. Subsequent concerns about the health of oyster stocks and collection practices resulted in first industry regulations. During the phase of early commercialisation, the industry had to respond and manage the first oyster disease outbreak of which others should continue to plague the industry.

2.5.3 Gradual expansion (1910s - 1950s)

During the 1910s and 1920s oyster farmers noticed that oysters growing on elevated structures above the ground grew faster and were less susceptible to mudworm infestations. This led to the development of off-bottom cultivation methods. Initially this involved catching spat and growing oysters on rocks which could be stood on edge to elevate the growing oysters above the mud (Clarke, 2013). The farmers also observed that oyster larvae could be caught in profusion on bundles of thin black mangrove sticks (stoops) which could then be divided up and stuck vertically into the ground (stuck sticks) to grow the oysters to a marketable size (Clarke, 2013). As black mangrove timber was in abundant supply this method of stick cultivation quickly replaced the laborious rock cultivation method (Clarke, 2013). However, the depletion of suitable black mangrove sticks by the 1940s led to the development of the coal-tarred sawn hardwood stick (Clarke, 2013). These readily available and easy to handle oyster sticks laid the foundation for the rapid expansion of the NSW oyster industry (Clarke, 2013)[2]. However, similar to the black mangrove sticks, the coal-tarred sawn timber stick proved to be not very durable in a marine environment (Ogburn, 2011).

In the early 1920s first observations of winter mortality in SROs, caused by a parasite *M. roughleyi*, were reported from the Georges River (see Figure 2.4) (Nell, 2001). Oysters in the area between Port Stephens and the Victorian border were and still are particularly susceptible to winter mortality (Nell, 2001). Winter mortality has not spread north of Port Stephens, suggesting that there is a northern limit to the spread of this parasite (Nell, 2001).

The total industry production in NSW increased gradually to about 5,140 metric tons of oysters by the end of the 1950s (Pease & Grinberg, 1995) (Figure 2.6). Major oyster producing estuaries during this period included Port Stephens, Georges River and Hawkesbury River (see Figure 2.4).

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[2] Spat was caught on sticks placed horizontally at or just above settlement range of the oysters (Ogburn, 2011). About six months after spat became attached the sticks were moved to upriver depots during winter and they were placed on growing leases for maturity (Ogburn, 2011). Alternatively, the oysters were knocked of the sticks when they were more than 2 years old and placed in tarred hardwood and wire mesh trays until harvest (Ogburn, 2011).

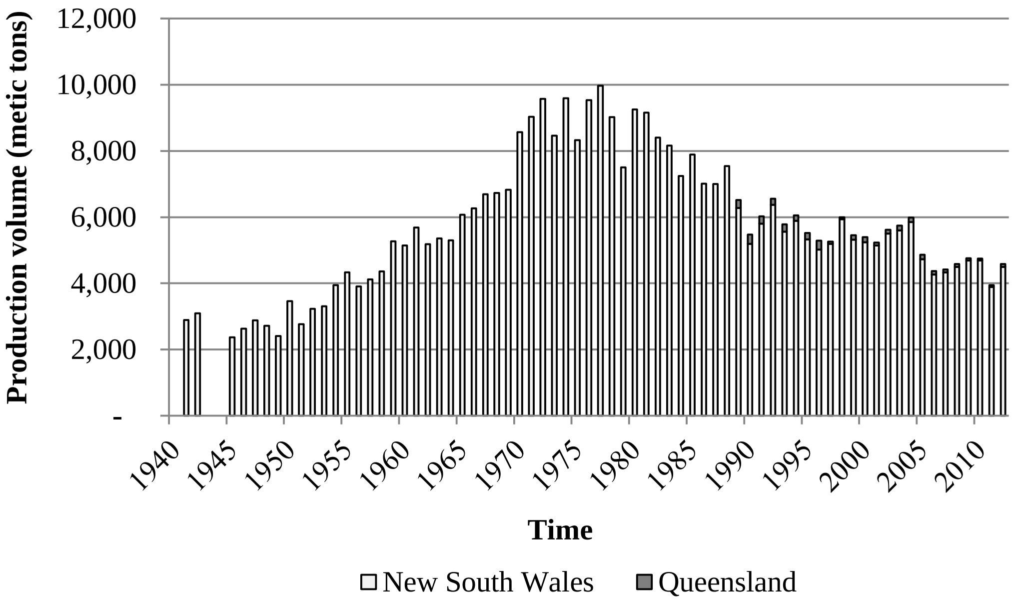
Although the oyster production in NSW recovered quickly from mudworm infestation and winter mortality at the beginning of the century, the industry in Queensland significantly shrank during this period (Lergessner, 2006; G. Smith, 1981). Until the 1920s the oyster industry in Moreton Bay was not only the largest but also the single most important industry in that region (Lergessner, 2006). It is estimated that about 96 boats, 137 oystermen and 665 oyster banks (see bank oysters above) were involved in Queensland's oyster industry during 1911-20 (Lergessner, 2006). The decline in oyster production in Queensland was linked to the mudworm infestation[3], stock theft, severe depletion of natural oyster banks, increasing competition from cheap New Zealand dredge oysters, rise of the industry in NSW and, thus, decreased demand for oysters from Queensland, industry regulations that encouraged only limited protection of natural oyster grounds from overexploitation and the lack of capital investment to modernise aquaculture infrastructure (Lergessner, 2006; G. Smith, 1981, 1985). The lack of infrastructure investment was partly due to a lack of security of oyster bank tenure with licences renewed annually and six months eviction notice only required (G. Smith, 1985)[4].

The start of World War I and decreasing demand for oysters from the southern States as well as the influenza epidemic after the war were seen as further reasons for the decline of the Queensland oyster industry during this period (G. Smith, 1985). By the early 1920s the oyster production Queensland only returned about 2,000 bags (approximately 125 metric tons) per annum (G. Smith, 1985).

[3] Mudworm first occurred in southern Queensland in the Coomera River in 1885 (G. Smith, 1981).

[4] Unfortunately, there is no information available about the allocation process for bank oyster tenure in Queensland. The allocation of leases for dredge sections in Queensland was undertaken either auction or tender (G. Smith, 1985).

Figure 2.6: Annual production volume of SROs over time



Notes: Data for 1940, 1943 and 1944 not available for NSW production. Time series data for the period 1940-1989 was not available for Queensland. Source: Data for the period 1941-1992 retrieved from Pease and Grinberg (1995), data for period 1993-2012 from ABARE (1993, 1994, 1995, 1996, 1997, 1999, 2000, 2001, 2002, 2003b, 2004, 2005, 2006, 2007, 2008, 2009), ABARE-BRS (2010), ABARES (2011, 2012, 2013).

During the period between 1910s and 1950s the SRO industry grew as measured by increased total output. However, spatially, the production of SROs shifted to NSW, with significant decreases in SRO output in Queensland. Whilst there was significant innovation in production methods during this period, the Queensland SRO producers were affected particularly hard by disease, decreasing local demand and lack of infrastructural investment. Depletion of oyster stocks was also a key reason to the decline in Queensland SRO production, indicative of a local regulatory framework that limited the conservation of natural oyster beds.

2.5.4 Growth and maturity (1960s - early 1980s)

During the 1960s the NSW SRO industry experienced a consistent growth in production volume mainly due to improved stick and tray cultivation, which remained the predominant production method, and an increase in the number of oyster aquaculture lease areas (Nell, 2001).

During this period it was common to transfer oysters from estuary to estuary in order to take advantage of different fattening conditions across estuaries. This practice was known as “highway oyster farming” and was particularly popular in the mid-1960s around the Port Stephens production areas (Nell, 2001). This practice continued until the mid-1980s. During this time Port Stephens became the major oyster nursery in NSW and the largest oyster producing estuary and it is estimated that around 75 per cent of all oyster harvest in NSW originated from Port Stephens (Ogburn, 2011).

Food safety issues from contaminated shellfish became an increasing public concern during the 1960s and 1970s. For example, in 1978 an incident involving over 2,000 reported cases of viral gastroenteritis (*Norwalk virus*) was linked to the consumption of oysters farmed in the Georges River (Grohmann *et al.*, 1980; Linco & Grohmann, 1980; Murphy *et al.*, 1978). In response to this incidence, depuration[5] of oysters for a period of seven days prior to sale became compulsory in 1983 (Ogburn, 2011). This health and food safety risk management approach was the sole in place and believed to provide sufficient protection to oyster consumers (Ogburn, 2011). It is speculated that the increasing occurrence of contaminated shellfish coincided with increasing coastal development during this period (G. Smith, 1985).

Another disease affected the industry during this development stage. The QX ("Queensland unknown") disease, caused by a parasite called *Marteilia sydneyi*, first emerged in Queensland in the late 1960s (Wolf, 1972). QX infections commonly occurred between January and April and lead to a loss in oyster health and eventually death by starvation (NSW DPI, 2013b). In 1974/75 the first major outbreak of the QX disease occurred in a number of the northern NSW estuaries, which led to a significant decline in production in these estuaries (Nell, 2001). It is believed that the translocation of oysters between estuaries may have caused the spread of QX disease infected stock from Queensland the northern NSW (Nell, 2001). Oyster production in most regions affected by QX disease did not recover and, therefore, many oyster farmers left the industry at that time (Nell, 2001; O'Connor & Dove, 2009).

During this development stage of the SRO industry, first observations of the habitat invasive Pacific oyster were made in Pambula River, southern NSW, in 1967 (Wolf & Medcof, 1974). It is thought that its occurrence is a result of wild spawning of Pacific oysters that had been introduced to Victorian estuaries by the CSIRO in the 1950s (Wolf & Medcof, 1974). Due to the potentially negative impact of Pacific

[5] Purification of oysters needed to be conducted in onshore depuration tanks.

oysters on the NSW SRO industry, earlier attempts to land Pacific oysters from Japan in the 1940s resulted in the shipments being condemned and destroyed by the NSW Government (Malcolm, 1987). The spread of the invasive Pacific oysters continued along the NSW coast until it reached Moreton Bay in 1975 (Wolf & Medcof, 1974). The industry management reacted with restricting transfers of oysters to northern estuaries thereafter to prevent the spread of Pacific oysters with limited success as next development stage of the industry will show (Nell, 2001).

The SRO oyster production in NSW peaked in the mid-1970s with a production volume of about 9,970 metric tons of oysters per annum (Figure 2.6) (Pease & Grinberg, 1995). Major oyster producing estuaries in NSW were still Port Stephens, as well as Georges River and Hawkesbury River. In Queensland the production volume remained low during this period particularly due to the QX disease and increasing urbanisation that caused water quality of Moreton Bay to decline (Lergessner, 2006; G. Smith, 1985).

Improvement in production methods, such as “highway oyster farming”, and the increase in the number of lease areas becoming available led to a phase of growth and maturity for the SRO industry. The industry was vibrant and experiencing unprecedented returns during this period. However, this success was only limited to NSW farming areas and first occurrences of the QX disease and Pacific oysters signalled the beginning of a significant decrease in the growth of SRO production. The occurrence and spread of the QX disease brought the ”highway oyster farming” to an end.

2.5.5 Consolidation and status quo (mid 1980s - present)

Diseases

The current development stage of the SRO industry is characterised by intensifying issues with diseases. For example, production of SRO oysters in the Georges River and in the Hawkesbury River collapsed in 1993/94 and again in 2002-04 due to the QX disease. As the disease appeared to have become endemic, SRO production was abandoned altogether in these two estuaries. Other estuaries, such as the Tweed, Richmond and Macleay Rivers, continued to be affected until this day (Ogburn, 2011). The precise cause of the occurrence of the parasite and how it affects SROs remains unclear. However, environmental and nutritional factors are believed to contribute to the oyster's susceptibility for the QX parasite and their limited defences against it (Green & Barnes, 2010b; NSW DPI, 2013b). Hatchery-produced QX resistant SROs developed by NSW Department of Primary Industries (NSW DPI) are now being cultivated in the QX affected Georges and Hawkesbury Rivers (Steve McOrrie, NSW Department of Primary Industries, personal conversation, 5 November 2013). However, production remains small at this stage (Steve McOrrie, NSW Department of Primary Industries, personal conversation, 5 November 2013).

In addition, winter mortality continues to occur on a highly variable and localised basis in the estuaries south of Port Stephens. Affected areas can experience stock losses of about 10-20 per cent on average, in extreme cases even up to 90 per cent (Steve McOrrie, NSW Department of Primary Industries, personal conversation, 5 November 2013). Fortunately, mudworm infestation is nowadays controlled by well established stock management practices (Steve McOrrie, NSW Department of Primary Industries, personal conversation, 5 November 2013). Other factors that can also result in losses of SRO stocks are heat kill (Ogburn, 2011) and algal blooms (Diggles, 2013).

Ecological competition from the Pacific oyster

During the early 1980s Port Stephens remained the main oyster nursery hub for the entire SRO industry (O'Connor & Dove, 2009). However, this came to an end in the mid 1980s with the infestation of the Port Stephens estuary by Pacific oysters (O'Connor & Dove, 2009). Pacific oysters are non-native to Australia and are habitat invasive. This implies that Pacific oysters can outcompete native oyster species for nutrients and physical space. In order to avoid a spread of the Pacific oyster, this oyster species was declared a noxious fish in 1986 in all NSW waters except in Port Stephens (Ogburn, 2011). Control measures were put in place to limit the spread of Pacific oysters to other estuaries (Ogburn, 2011). This risk reduction measure was believed to avoid a permanent spread of this invasive species (Ogburn, 2011). The subsequent cost of control and management of the Pacific oysters were estimated to about 100 million Australian Dollars (Ogburn, 2011). Nevertheless, due to the already overwhelming numbers of wild Pacific oysters present at Port Stephens, their cultivation was permitted there in the early 1990s and remains to be the only estuary in NSW where wild Pacific oysters are grown today (Steve McOrrie, NSW

Department of Primary Industries, personal conversation, 5 November 2013). Production of Pacific oysters in the Port Stephens estuary was about 2,720 bags (which equals approximately 170 metric tons) in 2011/12, which equates to about 6 per cent of total oyster production volume in NSW (NSW DPI, 2013a). Industry wide surveys continue to be conducted to monitor the spread of Pacific oysters to other NSW estuaries. The most recent survey that was undertaken in all NSW estuaries in 2010 revealed that wild Pacific oysters were absent in all estuaries north and including Macleay River and present in all other estuaries surveyed (see Figure 2.4) (NSW DPI, 2012). In order to prevent a further spread of wild Pacific oysters, farmers need to report any non-native oyster specimens to the regulatory authority and are required to comply with the current rules regarding the movement of oysters between estuaries (NSW Government, 2014a).

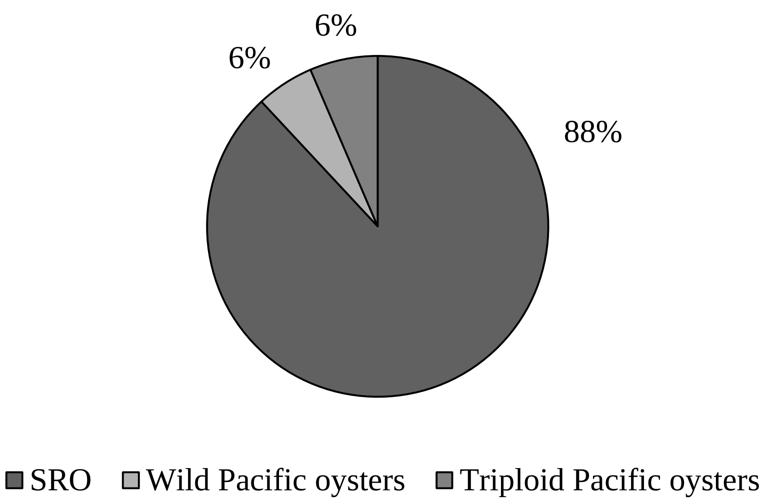
Following the completion of favourable environmental impact assessments[6], the industries' key regulatory authority in NSW (the NSW Department of Primary Industries (NSW DPI)), approved the cultivation of triploid Pacific oysters[7] in the Georges and Hawkesbury Rivers in 2004 and 2005 respectively. In both estuaries SRO production had been eradicated by QX disease. Triploid Pacific oysters are produced in shellfish hatcheries and then transferred to estuaries for grow out (Syvret *et al.*, 2008). Due to their functional sterility, triploid Pacific oysters are considered to be non-invasive (Syvret *et al.*, 2008). Today, the cultivation of triploid Pacific oysters is also permitted in Wallis Lake, Crookhaven, Shoalhaven and Clyde Rivers as well as Wapengo Lagoon (see Figure 2.4) (NSW DPI, 2014b). This shows that SRO growers have already started to diversify their production. Triploid Pacific oyster cultivation approvals also require the completion of favourable environmental impact assessment as set out in the NSW Oyster Industry Sustainable Aquaculture Strategy (OISAS) (NSW DPI, 2006). The triploid Pacific oysters, are of particular

[6] These assessments of the environmental impacts of aquaculture activities were authorised under a proposed fishery management strategy in NSW. The term 'environmental' includes biological, economic and social aspects. The environmental impact statement predicts the impacts for aquaculture practices on target species, important fish habitat, the broader ecosystem, and economic and social issues. It also considers the impact on the resource from other fishing activities and other non-fishing activities.

[7] Pacific oysters normally have two sets of chromosomes, under a patented process tetraploid and diploid Pacific oyster parents can be mated in a shellfish hatchery to produce offspring with three sets of chromosomes. However, there is evidence that triploid Pacific oysters are not completely sterile and cannot provide complete containment (Gong *et al.*, 2004). Yet, triploids have greatly reduced reproductive potential compared to diploid stocks and are therefore selected for aquaculture and considered non-invasive (Gong *et al.*, 2004).

commercial interest for oyster farmers since they are not affected by QX disease and grow significantly faster than the native SRO and, thus, reach a marketable size earlier (Nell & Perkins, 2005; NSW DPI, 2005). However, the farming of wild and triploid Pacific oysters is not free of potential issues. For example, in 2010/2011 an outbreak of the Pacific Oyster Mortality Syndrome (POMS)[8] affected populations of wild Pacific oysters in Port Jackson/Sydney Harbour and wild and farmed triploid Pacific oysters in Georges River/Botany Bay (NSW DPI, 2014c). In early 2013, POMS was detected in farmed triploid Pacific oysters in Hawkesbury River (NSW DPI, 2014c). In 2011/12 the total production volume of triploid Pacific oysters in NSW was about 5,463 bags (approximately 341 metric tons) valued at 2.7 million Australian Dollars (NSW DPI, 2013a). The current share of wild and triploid Pacific oysters of the total oyster production in NSW is about 12 per cent (NSW DPI, 2013a) (see Figure 2.7). Thus, the majority of oysters produced in NSW today are SROs.

Figure 2.7: Current composition of the NSW oyster industry



Source: NSW DPI (2013a).

The implications of the introduction and management of the Pacific oyster in NSW remains significant for the SRO industry, economically and politically (Ogburn, 2011). By allowing the cultivation of triploid Pacific oyster industry in

[8] The Pacific Oyster Mortality Syndrome (POMS) is a diseases caused by a virus called OsHV-1 micro variant (Green *et al.*, 2014; Paul-Pont *et al.*, 2013). This disease affects only Pacific oysters and can lead to rapid stock mortality within days of initial detection (Paul-Pont et al., 2013). This disease has first been recorded in 2008 in France and also affected Pacific oyster industries in United Kingdom, Jersey, Ireland, Spain, The Netherlands and the United States (Paul-Pont et al., 2013).

NSW the industry management successfully saved oyster businesses that were affected by the QX disease (mainly Hawkesbury and Georges Rivers). However, these decisions may have also contributed to additional pressure on the remaining SRO growers in the market. In Queensland, all Pacific oyster production remains prohibited to date.

Catchment and coastal development implications for food safety

The SRO industry has also been affected by increasing development of river catchment and coastal areas in recent times (O'Connor & Dove, 2009). A decline in water quality caused for example by human faecal contamination, run-off from acid sulphate soils in a number of coastal flood plains and intense rain periods causing prolonged freshwater events have severely affected oyster production (O'Connor & Dove, 2009). In addition, coastal development may also impact the environmental carrying capacity of estuaries and thus the natural supply of SRO spat along the Australian east coast. Yet, this has not been addressed in the literature at this stage.

However, as a consequence of a decline in water quality and related increasing food safety risks associated with the consumption of oysters, the NSW Shellfish Quality Assurance Program was established in 1997. This program, which is administered by the NSW Food Authority under the *Food Regulation 2010* (NSW Government, 2013), controls the harvest and sale of oysters grown for human consumption in NSW waters. It classifies oyster harvest areas in terms of their public health risk and sets mandatory water quality monitoring, harvest and depuration standards and procedures. The NSW Shellfish Quality Assurance Program is co-funded by the NSW oyster industry and the NSW Government. The Queensland oyster industry is regulated by the *Food Production (Safety) Act 2000* (State of Queensland, 2009) and the *Food Act 2006* (State of Queensland, 2006), and mainly administered by Safe Food Queensland. Food safety regulations are associated with compliance costs for oyster farming businesses. Ongoing coastal development may continue to impair estuarine water quality on Australia’s east coast and as such the cost of dealing with these externalities could have ramifications for the profitability of oysters businesses in future.

Climate change

Recurrent and unprecedented flood events in the recent past had a significant impact on oyster farming business, particularly, in estuaries located north of Port Stephens (Steve McOrrie, NSW Department of Primary Industries, personal conversation, 24 March 2014). Water temperature and salinity levels are two important variables that can affect oyster development in different life stages (Dove & O'Connor, 2007). With projected annual warming of sea surface temperature (that effects estuary water temperature) and expected increasing variability in precipitation and increasing evaporation (which both affect salinity levels in estuaries), the natural productivity of the oyster industry may by affected in the future (CSIRO & Bureau of Meteorology, 2007; Leith & Haward, 2010). Furthermore, increasing ocean acidification due to climate change may likely have a negative impact on oyster larvae development (Parker *et al.*, 2009, 2010) and consequently on the productive capacity of the industry. Therefore, climate change will likely add an additional strain to the industry's future sustainability.

Environmental risks of oyster farming

The impact of oyster cultivation on estuary health has gained increased public interest in the past decade and prompted pressure on the industry to improve oyster lease maintenance. For example, the common use of coal tar as a preservative coating on timber sticks to reduce attack by marine boring organisms was found to pose contaminant risks for the marine environment and health and safety concerns for workers and consumers (Ogburn, 2011). Furthermore, the environmental risk associated with tarred oyster farming infrastructure left on derelict leases has resulted in high disposal costs for both industry and governments in NSW and Queensland (Katie Sachs, NSW Department of Primary Industries, personal conversation, 16 December 2013). As a consequence, the NSW *Fisheries Management Act 1994* now requires the lodgement of environmental performance bonds[9] covering oyster lease areas held by individual oyster farmers. To ensure farmer compliance with the responsibilities regulated under the *Fisheries Management Act 1994*, NSW DPI conducts state-wide inspection audits of all leases once every three years. Failure to comply with these directions can result in fines or

[9] The bond is either a cash deposit or bank guarantee of up to 1,000 Australian Dollars per hectare or an annual contribution of 40 Australian Dollars per hectare (NSW DPI, 2014b).

remediation by NSW DPI. As a consequence of ongoing issues with the traditional, unsuitable farming equipment, alternatives have been developed, such as environmentally sustainable and recyclable plastic infrastructure, which is durable, economical and suitable for oyster cultivation and which has been gradually introduced by farmers since the early 2000s (Ogburn, 2011). Furthermore, oyster farmers are increasingly participating in voluntary environmental stewardship schemes, such as Environmental Management Systems (*e.g.*, funded by the Australian Government's Caring for our Country program), as these increase their prospects of receiving other grants for farm infrastructure improvements.

Market, production scale and economic performance

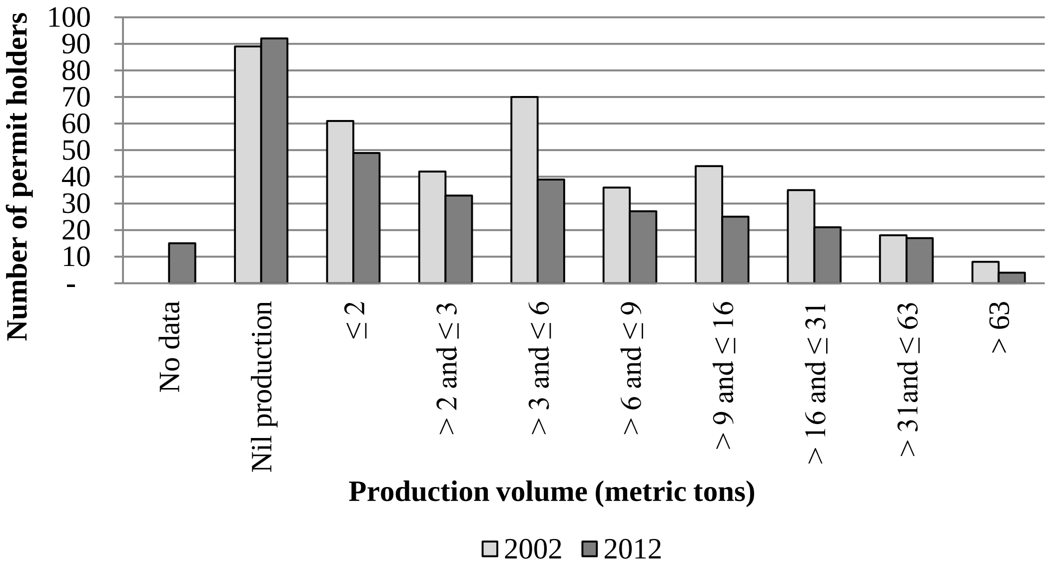
The SRO industry experienced a significant reduction in output during the present development stage of the industry. As discussed earlier, the main reasons for this development are the environmental issues that the industry is facing. The production volume in NSW decreased from 9,250 metric tons in 1985 to about to about 4,500 metric tons in 2012 (NSW DPI, 2013a; Pease & Grinberg, 1995) (see Figure 2.6). In Queensland a similar trend was observable, while the production volume was about 245 metric tons in 1998, the production volume declined to approximately 85 metric tons in 2012 (ABARE, 1991; ABARES, 2013) (see Figure 2.6).

The major SRO producing estuaries are currently Wallis Lake, Port Stephens and Clyde River (see Figure 2.4).

The market for SROs remained almost exclusively domestic throughout the industry's development. Less than one per cent of produced SROs are currently sold to overseas markets (NSW DPI, 2013a).

The decline in SRO production volume over time is mirrored in the number of oyster farmers present in this industry. For example, the number of oyster aquaculture permit holders in NSW declined from 406 in 2002 to 322 in 2012 (Figure 2.8) (2003, 2013a). The distribution of the production scale within the industry has broadly remained unchanged over the period 2002-2012 (Figure 2.8) (NSW DPI, 2003, 2013a). Figure 2.8 also illustrates that there is a high number of oyster farmers that produce no oysters or relatively small quantities of oysters per annum (less than 3 metric tons).

Figure 2.8: Oyster aquaculture permit holders and scale of production in NSW



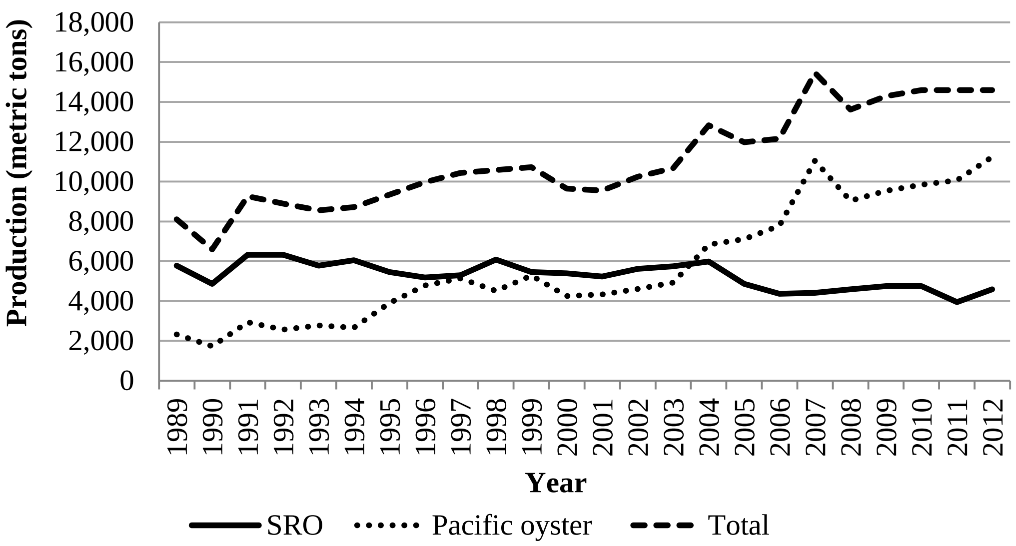
Source: NSW DPI (2003, 2013a).

The proportion of SRO oysters sold as larger size plate reduced in the past period in favour of smaller bistro and bottle grade oysters (O'Connor & Dove, 2009). The cause for the trend towards the sale of smaller oysters is not solely driven by demand (O'Connor & Dove, 2009). It is likely that farmers use this strategy as an approach of dealing with the increased stock loss risk and to maintain their business cash flow particularly on the NSW south coast where the risk of winter mortality is high.

With a total production value of 28.8 million Australian Dollars in 2012 (ABARES, 2013), the SRO industry today contributes only a small proportion to the total aquaculture production in Australia.

A possible market-based explanation for the observed decline in SRO production could be the increasing competition from an expanding Pacific oyster industry in TAS and particularly in SA from the early 1990s. Pacific oysters were deliberately introduced to TAS in the 1950s (Mitchell *et al.*, 2000) and to SA in the 1960s (PIRSA, 2003) in order to establish a new industry in cooler waters of southern Australian States where attempts to culture SROs failed (Thomson, 1952). Different to the SRO industry, the Pacific oyster industry exclusively relies on hatchery grown spat. The Pacific oyster industry has expanded its production volume significantly since the late 1990s due to increased access to new and more productive sites in SA (Trudy McGowan, South Australian Oyster Growers Association, personnel communication, 5 December 2011). Since 2004 the supply of Pacific oysters exceeds the market supply of SRO oysters (Figure 2.9). However, there is currently no detailed information available about possible oyster market conditions that may have affected the SRO price formation and the demand for SROs and subsequently the market supply of this native species.

Figure 2.9: Edible oyster production in Australia, 1989-2012



Source: ABARE (1991, 1993, 1994, 1995, 1996, 1997, 1999, 2000, 2001, 2002, 2003b, 2004, 2005, 2006, 2007, 2008, 2009), ABARE-BRS (2010), ABARES (2011, 2012, 2013).

Both edible commercial oyster industries have been engaged in the Oysters Australia Benchmarking Program, commissioned by Oyster Australia (see below), for several years. This Benchmarking Program conducts assessments of oyster farm business performances (that includes SRO and Pacific oyster businesses). The analysis of data collected by the Benchmarking Program focuses on basic production and financial indicators against which individual oyster farm performance can be compared. However, only a small number of SRO oyster farmers participated in this program in the past, which is not free of charge. The findings from the Benchmarking Program are reported annually in a summary that is publically available (Rural Directions, 2013). Unfortunately, the findings from the Benchmarking Program do not provide sufficient scope and detail of analysis, and also lack an adequate sample size (*e.g.*, only 6 SRO farmers participated in 2012) as a basis for industry management decisions about business performance-related matters.

SRO farmers, farming associations and representative industry bodies

There are currently 322 permit holders for SRO aquaculture in NSW (NSW DPI, 2013a) and 69 in Queensland (Wingfield & Heidenreich, 2013).

In 2001, White (2001) estimated that the NSW oyster industry provided employment for about 1,600 people and that every direct job created up to three indirect jobs. It is likely that this estimate has decreased significantly with the decreases in SRO production volume and the decline of the number of oyster aquaculture permit holders over the past decade (Figure 2.8).

Unfortunately, there is no information available about SRO farmers. Socio-economic characteristics, such as age, experience in the industry, educational attainment, and household income could provide valuable information about who operates in the SRO industry. Socio-economic information about the industry members could potentially also provide some explanations for the current status of the industry.

The SRO industry is represented by a number of organisations. There are currently three SRO farming association, the NSW Farmer's Association – Oyster Section, Oyster Farmer's Association of NSW, and the Queensland Oyster Grower's Association Inc. The role of these associations is mainly the provision of advocacy on State level. The major bodies that represent the industry on a national scale are the National Aquaculture Council (NAC), the Shellfish Industry Council of Australia (SICOA) and Oyster Australia. NAC and SICOA provide advocacy and representative role at the national level to the Australian Government and offer some research coordination that relate to the SRO industry. Oyster Australia was founded in 2011 by Australia's community of oyster growers, which includes SROs, Pacific oysters and native flat oysters. This institution also offers advocacy, research and development coordination nationally in order to increase oyster production, consumer satisfaction and, thereby, oyster consumption in Australia and to build capacity, leadership and confidence in the industry.

Innovation

Issues with diseases and pests in the past prompted the SRO industry to invest in innovative ways to ensure a stable production volume and, in effect, to secure regional employment in the industry.

The previously common stick cultivation method for SROs started to become unfeasible in the 1980s in areas affected by the invasive Pacific oyster as these oysters settled and flourished on this type of oyster furniture and were impossible to manage. As a consequence, a new oyster cultivation method called single-seed oyster production was developed in 1990s[10]. Advantages of single-seed cultivation include improved shape and growth of oysters. However, this cultivation method requires a regular grading and sorting of oysters (Ogburn, 2011). The uptake by SRO industry of this new cultivation technique was initially slow; however, in recent years its use has increased dramatically, particularly, in southern NSW (Steve McOrrie, NSW Department of Primary Industries, personal conversation, 24 March 2014).

A selective breeding program[11] for SRO spat in hatcheries was established by NSW Fisheries in 1990 with the aim of selecting SROs for faster growth (Ogburn, 2011). Current breeding programs provide increasing success rates in oyster larval production; however, research on improving selectively bred spat is ongoing (O'Connor & Dove, 2009). The breeding program is currently co-funded by the oyster industry and the NSW Government (mainly through in-kind support), and significantly relies on liaison with farmers and their demand of oyster traits and spat volume. The number of selectively bred seeds is estimated at around 40 million spat, which equates to around 30 per cent of current industry demand (O'Connor & Dove, 2009). The financial outlay of hatchery spat is considerably larger than for natural spat and may, therefore, not be affordable for all growers. Nevertheless, ongoing issues with diseases in wild oyster stocks caused selectively bred stock to become more attractive (Nell, 2001).

Innovation within the industry was supported in recent years by a relatively large body of research that focused on the biology of the SRO and on effects of various environmental factors on the growth and health of this oyster species. Main

[10] Single-seed cultivation refers to the collection method of oyster spat and involves growing single unattached oysters in either baskets or trays. Single unattached oyster can be purchased from shellfish hatcheries or can be produced by removing wild naturally settled oysters at an early age from plastic settlement collectors. Wild spat is caught on flexible plastic slates and scraped from these collectors after the oysters reached a size of 3-8 mm, they are then placed on purpose-build 3 mm mesh trays or other containers (Ogburn, 2011). The oyster furniture is then transported to areas of low spatfall for maturing (Ogburn, 2011).

[11] This includes selection of certain genotypes and the removal of undesirable traits. The selection will result in establishing genetically favourable traits in the brood stock (FAO, 2004).

areas of research in the scientific literature covers includes diseases (*e.g.*, Green & Barnes, 2010a, 2010b; Green *et al.*, 2011; Peters & Raftos, 2003), selective breeding (*e.g.,* Dove & O'Connor, 2012; Hand *et al.*, 2004; Newton *et al.*, 2004; Simonian *et al.*, 2009), pollution (*e.g.*, Andrew-Priestley *et al.*, 2012; Rubio Zuazo, 2008; Thompson *et al.*, 2012), and climate change (*e.g.*, Parker *et al.*, 2009, 2010, 2011; Parker *et al.*, 2012).

A research area that has recently received some attention is the supply chain of SROs. For example, Mueller Loose *et al.* (2013), Kow *et al.* (2008) and Liu *et al.* (2006) investigated consumer preferences for oysters in Australia and Cominski (2009) and Hobday *et al.* (2013) provided information about the structure of the supply and value chains of the SRO industry (more detail about supply and value chains is provided later). However, social, business and economic aspects that concern the SRO industry remain underrepresented in the current research efforts.

Industry regulation and management

The industry was initially regulated to stop the overexploitation of natural oyster stocks (see section 2.5.2). Today, the industry remains regulated in order to provide oyster farmers secure property rights for their leases. Due to the juridical separation of States in Australia, the SRO industry in NSW and Queensland is regulated and managed by two different government institutions, which are the New South Wales Department of Primary Industries, Fisheries Division, and the Queensland Department of Agriculture, Fisheries and Forestry, Aquaculture Division (QLD DAFF).

The government involvement in the management of the SRO industry is a classical management form found in many fisheries and aquaculture industries worldwide. The fundamental rationale for the government involvement in the oyster fishery management is at least threefold: 1) to avoid negative externalities from the exploitation of common pool resources (efficiency reason); 2) to ensure a fair distribution of opportunities and incomes among the participating industry members (equity reason); and 3) to have authority and resources sufficient to implement management schemes (administrative reason) (based on Jentoft (1989)).

More specifically, the industry regulatory and management responsibilities include, for example, the assessment and declaration of aquaculture areas, monitoring and enforcement of habitat protection and compliance as well as development of policies, standards and guidelines (efficiency reason). Furthermore, the location of oyster areas is determined by the regulatory authorities to safeguard the optimal carrying capacity of estuarine ecosystems and to avoid conflicts among the multiple user of the ecosystem (*e.g.*, fishing, tourism).

Other tasks of the industry management include lease and permit allocation (equity reason), the collection and collation of production data, and the coordination of research (administrative reasons).

The management tasks of the SRO industry include 'consultative' arrangements, which involves an advisory board in which representatives of the industry are consulted by the government before regulations are introduced (Jentoft, 1989). The governments in both States have chosen a direct regulation approach by employing an aquaculture area licensing mechanism which seeks to limit production output[12].

Both government institutions are also responsible for the development of industry strategies in partnership with the industry members, local communities and other stakeholders. These strategies set out an industry development vision or objectives, best oyster aquaculture standards and guidelines, environmental objectives and monitoring standards, aquaculture area planning and approval processes, as well as risk management guidelines.

Realistic medium-term development objectives are important for fishery industries as they designate assurance of the fishery management in the future of the industry to all stakeholders. Accordingly, the NSW Oyster Industry Sustainable Aquaculture Strategy, which was last reviewed in 2014, (NSW DPI, 2014b) states the following goal*:*

"The vision of this strategy is to achieve the sustainable production of 7,500 tonnes of premium NSW oyster products for domestic and export markets by 2020....The vision of a healthy and sustainable NSW oyster industry remains and despite a decreasing production trend, an aspirational production goal has also been retained. This is in the belief that the recent production losses from floods and

[12] The alternative to the direct regulation approach is indirect regulation which controls the production inputs, *e.g.*, manpower, equipment (Jentoft, 1989).

disease events will be overtaken by increases in production from new species, new investment and from innovative culture technology."[13]

The Oyster Industry Management Plan for Moreton Bay Marine Park (QLD DPI&F, 2008a) describes development strategies for the SRO industry in Queensland and is subject for revision in 2014. The objectives here are to increase production, to promote the commercial industry development and to improve the image of the industry (QLD DPI&F, 2008a).

Detailed approaches and time lines that outline how these goals are expected to be achieved are not provided in either of the two industry development strategies. Furthermore, these strategies fail to explain how new investment and funding to develop innovative culture technology will be attracted and how the promotion of the industry and a better image of the industry will be achieved.

SRO supply chain and marketing

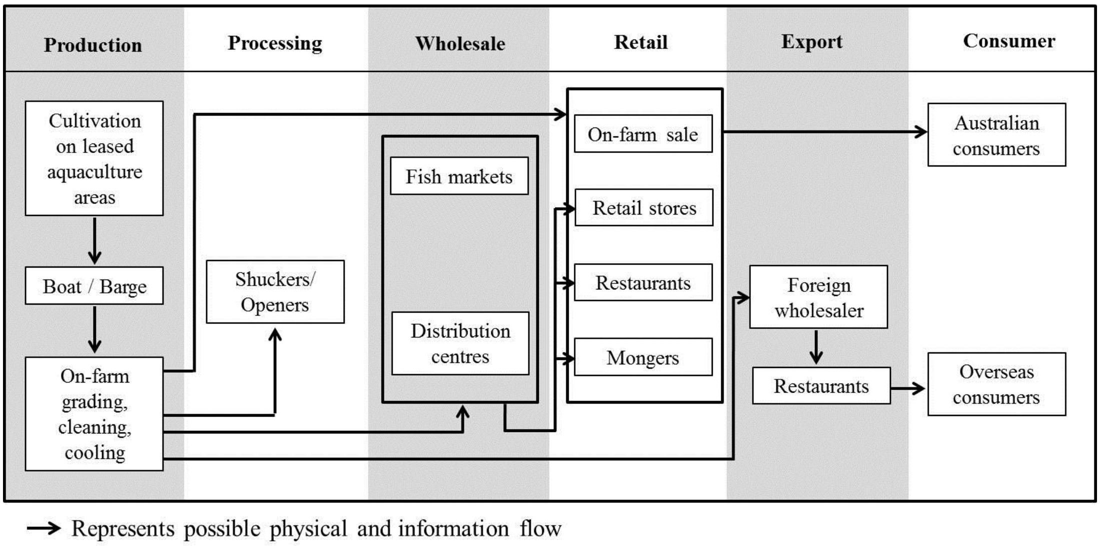
A supply chain is broadly defined as a network of organisations (*e.g.*, firms) or individuals that pass the products from initial producers/supplier to final consumers (Mentzer *et al.*, 2001). A description of SRO supply chain components was provided by Hobday *et al.* (2013) and Cominski (2009), which is illustrated in a simplified form in Figure 2.10. According to this supply chain, market institutions that link SRO producers with oyster consumers can include processors, wholesalers, retailers, and exporters.

The production component in the supply chain includes the cultivation, harvest, interim storage and transportation to markets of oysters. The processing stage comprises oyster openers (also called shuckers) who purchase the oysters from farmers and are paid for opening and packaging oysters which are then distributed to wholesalers, fish markets or distributed to different destinations (Cominski, 2009). The wholesale section of the supply chain includes either specialised oyster wholesalers who handle oysters exclusively or with only a few additional fish products; or seafood wholesalers who deal with a range of seafood products including oysters (Cominski, 2009). There are also cases in which wholesalers provide oysters processing services. The retail segment of the supply chain is

[13] For comparison, in 2012 about 4,600 tons of oysters were produced in NSW (ABARES, 2013). Thus, the goal for the NSW oyster industry is to increase its production volume by about 40 per cent by 2020.

comprised, for example, by on-farm oyster bars, restaurants, mongers and supermarkets. The small number of SROs that are exported to predominantly Asian markets are usually directly distributed from producers to export wholesalers and from there distributed directly to overseas restaurants (Hobday *et al.*, 2013). Consumption of SROs are mostly domestic.

Figure 2.10: SRO supply chain



Source: Adapted from Cominski (2009) and Hobday *et al.* (2013).

An assessment of how the performance of the production component of the SRO supply chain may affect the stability of the entire network would include an economic and environmental sustainability analysis of SRO production. However, as outlined in previous sections, research in this area has been limited at this stage. While there are currently no studies available that examine the mid-supply chain segments, there has been some research effort in investigating the consumer segment. The most prominent studies that examine consumer preferences for oysters (including SROs) in Australia include Mueller Loose *et al.* (2013), Kow *et al.* (2008), and Liu *et al.* (2006). Mueller Loose *et al.* (2013), for example, found that price and preparation format (*e.g.*, opened and unopened oysters) were the most important drivers of consumer choice for oysters, followed by region of origin, oyster species, and accompaniments (Mueller Loose *et al.*, 2013). In regard to the preference for oyster species, the authors provided evidence that consumers preferred SROs over Pacific oysters (Mueller Loose *et al.*, 2013). In addition, this study found that packaging format and claim (*e.g.*, carbon zero) had only minor influence on consumer choices of oysters (Mueller Loose *et al.*, 2013). Kow *et al.* (2008) provided evidence that consumer's preferred product form is half-shell fresh, grilled or Kilpatrick and that the majority of consumers purchase oysters in restaurants, fish shops followed by commercial markets. Liu *et al.* (2006) showed that consumers choice of 'dine in or out for oyster' is linked to factors like age, gender, residence, and product labelling. Furthermore, Liu *et al.* (2006) found that the frequency of eating oysters is influenced by age of consumers, packaging and price.

Kow *et al.* (2008) points out that the lack of branding and market development may have impeded oyster industry growth. All three studies on consumer preferences for oysters suggest that product differentiation by price, preparation format, region of origin and species may potentially be beneficial for increased consumer demand for SROs.

Closely linked to the concept of supply chain is the value chain, which is defined as value or feature added to the primary product by each level within the product's distribution network. Added value to oyster products typically occurs in form of grading, shucking (opening), packaging, cooling, storing and preparation for consumption, distribution and marketing by using labour and capital (see Figure 2.11) (Gundmundson *et al.*, 2006). Thus, each feature added also adds cost items and profit margins to the final product value.

Cominski (2009) presented estimations of a value chain for SROs which shows the presence of a significant difference in the price, which consumers pay for a dozen of oysters compared to the farm gate price that producers receive (see Figure 2.11). The total margin added to farm gate prices by the supply chain segments can amount to about 195 per cent (Cominski, 2009) depending on the size of oysters sold, the number of distribution intermediaries and location of consumers.

Figure 2.11: SRO value chain

Supply chain	Production	Interim transport	Processing	Wholesale	Retail (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%**

Notes: estimations for small bistro SRO sold by restaurant buffet in Western Sydney in 2009, margins do not include provisions for overhead, delivery costs, other handling or management costs. All values are in Australian Dollars. Source: Based on estimations in Cominski (2009).

Location, infrastructure, availability and access to market information and market power of individual businesses at each level of the value chain can affect how the final value of the product is distributed through the chain (Gundmundson *et al.*, 2006). SRO farmers are typically price takers as most growers don’t have the access to information about the market, final consumer and the production capacity to influence that market price. Cominski (2009) argued that there is a lack of price and consumer transparency within Australia’s oyster industry indicating that growers have little information about the consumers of their products and the prices that the consumer pay for the product. Furthermore, rigged price agreements between the wholesale level and oyster growers and the overall state of the economy can also affect the price of the SRO. Thus, farmers mostly receive the residual of the market price less marketing charges, packaging, and distribution prices (Cominski, 2009). Therefore, it is important to highlight that the price that consumers pay for final products does not reflect the share of farmers in the value chain and the profitability of their oyster businesses.

Cominski (2009) also showed that the majority of SRO oysters are sold by individual growers rather than any form of collective, such as marketing groups, co-operative or informal alliances of growers. Cominski (2009) argued that unless clearly unique characteristics to the products farmers offer are displayed to consumers, smaller growers will increasingly become price takers, resulting in lower average business returns.

2.6 CONCLUSION

The review of the available sources about the SRO industry shows that the SRO industry has a long history in Australia, dating back to the early European settlement. This industry was once thriving and leading in Australia's aquaculture sector. Environmental issues have challenged oyster farming throughout the industry's past. Increasing externalities from coastal development, *e.g.*, water pollution, have also affected the production of oysters and may also limit the carrying capacity of the ecosystems within which SROs thrive.

However, the industry has a demonstrated capacity to respond to such challenges with innovative production methods.

The industry's current development stage is characterised by an increasing range of environmental issues, which continue to affect its production volume negatively and, hence, its profitability. The increasing environmental issues demand a continuing investment in research and development of innovative technologies in order to minimise the environmental impact on oyster cultivation. However, while the search for and implementation of innovative technologies requires time, the industry output and economic return continues to decrease and so does the share of the industry in Australia's aquaculture sector.

The SRO industry offers employment and income to rural coastal communities. A continued decrease in production may imply that more growers may be forced to leave the industry as oyster farming becomes increasingly unprofitable. This will reduce income opportunities in rural coastal communities. In the most severe case, the loss of the traditional SRO industry would also mean a loss of considerable cultural and heritage value to the Australian society. This importance of the SRO industry provides a rationale for investigating approaches that could ensure future economic sustainability of SRO farming.

Environmental factors are indisputably a major cause for the current economic situation of the industry. However, there may be other factors, particularly factors of socio-economic nature that contribute to the status quo of the industry. The review presented in this chapter has identified a range of gaps in the knowledge about the industry. For example, the lack of information about socio-economic characteristics of SRO farmers, limitations in the knowledge about the Australian oyster market and the relationship of the key commercial oyster species within the market, the absence of information about the performance of oyster businesses and factors that influence their performance, as well as the lack of an analysis that investigates the potential economic impacts on the industry from climate change. The assessment and discussion of these topics is necessary to provide the current management of the industry an informed basis for decision-making about the future of the industry.

Given the findings from Chapter 2, the following Chapter 3 will provide an overview about the research design that was used in this dissertation.

Chapter 3: Research design

3.1 INTRODUCTION

From the review of the literature in Chapter 2, it becomes clear that there is only limited economic information available about the SRO industry. However, insight information into economic aspects is essential for the management of this industry as a basis for decision making about the future of this industry.

The purpose of this chapter is to provide a structured overview about which and how economic information about the SRO industry was generated in this thesis. The research design includes a hypothesis, a research objective and research aims. This chapter also provides an overview about the methodologies used in this thesis, the integration of analysis tools and the benefit and importance of information generated. Furthermore, information about data, ethics, limitations of the research scope and the contribution of this dissertation to the knowledge in the field will be outlined in this chapter.

3.2 HYPOTHESIS

The existing literature indicates that the once thriving industry, while continuously under significant environmental pressures throughout the past century, has seen a substantial decline in production output over the past 20 years. This suggests that factors beyond environmental causes may have been involved in the processes that lead to the industry's current dire state. Therefore, this thesis has been based on the following hypothesis: The decline in production of the SRO industry is not only a result of environmental issues but also caused by factors that are related to economic dimensions of the industry.

3.3 RESEARCH OBJECTIVE

The objective of the research described in this dissertation was to enhance the understanding of the economic status quo and potential future economic viability of the SRO industry.

3.4 RESEARCH AIMS

The hypothesis and the research objective led to the following key aims of this thesis:

Aim 1: Develop a socio-economic profile of the SRO industry;

Aim 2: Establish the market relationship of the key commercial oyster species in Australia;

Aim 3: Determine the level of productive efficiency and capacity utilisation observed for the SRO industry and identify drivers for these observations;

Aim 4: Estimate the simulated impact of environmental change and potential increases in Pacific oyster production on the future economic viability of the SRO industry; and

Aim 5: Derive focal areas for policy and management consideration that support a sustainable future development of the SRO industry.

These aims are further detailed below.

Aim 1: Develop a socio-economic profile of the SRO industry

It is known that the occurrence of diseases affected the economic viability of the industry in the past. However, there is very limited information available about the role of oyster farmers and how their characteristics may affect the economic sustainability of the industry. Information about oyster farmer's socio-economic characteristics, such as age, level of educational attainment, level of experience in the industry and household income, play a vital role in understanding the choice of farmer's business approaches, their participation in industry management, in facilitating innovation and in attracting investment.

For aim 1, a socio-economic profile of the SRO industry was developed to answer the following questions: What is the current socio-economic profile of the industry? What is the role of oyster farmer's demographics in the industry's economic performance? Are oyster farmers different to other population cohorts, *e.g.,* Australian agricultural farmers? What are oyster farmer's perception on the status quo and future for the industry?

In order to develop a socio-economic profile for the industry we used survey data which we collected in 2012. Findings about demographics, households and oyster farmer's perceptions offered suggestions for necessary changes to the socio-economic structure of the industry. This will be reported in Chapter 4.

Aim 2: Establish the market relationship of the key commercial oyster species in Australia

While the focus of the thesis is on the SRO industry, it is essential to understand the relationship of SROs to comparable products in the market environment. Prices for SROs have been falling in recent years. At the same time, the quantity of Pacific oysters has been increasing. While it could be assumed (using qualitative economic theory) that the latter is a key causal factor of the former, other factors may also have contributed to these price changes. Establishing and quantifying this relationship is vital if future price conditions – important for assessing the future viability of the industry – are to be estimated. If a close relationship to another product does exist, then continuing changes in the other industry will have further impacts on the SRO industry and vice versa. Hence, these potential impacts need to be identified.

Aim 2 initially analysed the market for edible oysters in Australia. The key questions addressed were: How does change in production affect oyster prices? How has increased Pacific oyster production affected the prices of SRO? Are the markets of the two key commercial species integrated (*i.e.*, is there effectively one market on which the two species are perfect substitutes) and does the law of one price hold? To address these questions, time series price data for the two major edible oyster species was used in an empirical analysis. If product aggregation can be identified, the two oyster species are competing in the same market and thus, any regulatory intervention directed at one species may indirectly affect the trade of the other.

Furthermore, aim 2 intended to model the demand relationship for the two commercial oyster species. The result provided a further indication of whether these species are treated as substitutes in a market environment and if so what the level of substitution is. This offered further information about how changes in the supply of both or either species (*e.g.*, through management changes) may affect the prices of each. This study is reported in Chapter 5.

Aim 3: Determine the level of productive efficiency and capacity utilisation observed for the SRO industry and identify drivers for these observations

Aim 3 investigated the productive efficiency and capacity utilisation of the SRO industry. The following questions were answered: What is the level of production efficiency in the industry? What are the main drivers of efficiency in the industry? Producer characteristics or external factors (*e.g.*, environmental factors)?

An analysis of the level of production efficiency, such as technical efficiency, scale efficiency, allocative efficiency and capacity utilisation, observed for the industry was performed. The outcome provided information about the ability of oyster businesses to obtain maximum output from a given set of inputs and whether the scale of business operations is optimal. Furthermore, the results allowed identifying the degree to which oyster businesses are adopting strategies that lead to an optimisation of revenues from the production process.

In an extension of the efficiency analysis it was then determined if oyster farmer characteristics and environmental factors affect the observed efficiency measures for the industry.

The overall outcome of aim 3 provided suggestions on optimal oyster area allocation. Furthermore, this study validated the role of demographic and environmental aspects in the economic viability of the industry. This study is presented in Chapter 6.

Aim 4: Estimate the simulated impact of climate change and oyster market dynamics on the future economic viability of the SRO industry

In aim 4, the future economic viability of the SRO industry under changing climate and market scenarios was investigated. The following questions were addressed: How is climate change likely to affect the economic viability of the industry in the medium term? Who may be the winners and who may be the losers? What is the likely combined impact of climate change and market dynamics on the industry’s economic future? Which of the two impacts may affect the industry most? In order to respond to these questions, a theoretical and empirical bio-economic model was developed. This model allowed the simulation of changes in revenue due to projected climate change and market dynamics. This research aim built on scientific projections for potential impacts of climate change on Australia and on the findings of aim 2 in which the market relationship between the key commercial oyster species in Australia was established. The results from aim 4 provided the basis for suggestions on how the industry may need to adapt to future changing environmental and market conditions. This study is presented in Chapter 7.

Aim 5: Derive focal areas for policy and management consideration that support a sustainable future development of the SRO industry

The future development prospects of the SRO industry may be influenced by changes in policies and industry management. The research question answered was: What are the key focal areas that policy and management should consider in order to support a sustainable future development of the SRO industry?

In order to respond to this question current polices and industry development plans were reviewed in the light of the findings for aims 1-4. The outcome of aim 5 was a list of recommendations which may support the sustainable future development of the SRO industry. A discussion of the findings from this dissertation and policy and management implications are presented in Chapter 8.

3.5 METHODOLOGIES

The thesis used a range of economic methodologies, *e.g.*, a survey, a cointegration analysis of time series, an efficiency and capacity utilisation analysis, and a revenue function analysis. The use of these methods attempted to bring together various types of assessments in the framework of this thesis in order to create new information that cannot be derived from a single analysis alone. A summary of the chosen research approaches is provided in Table 3.1.

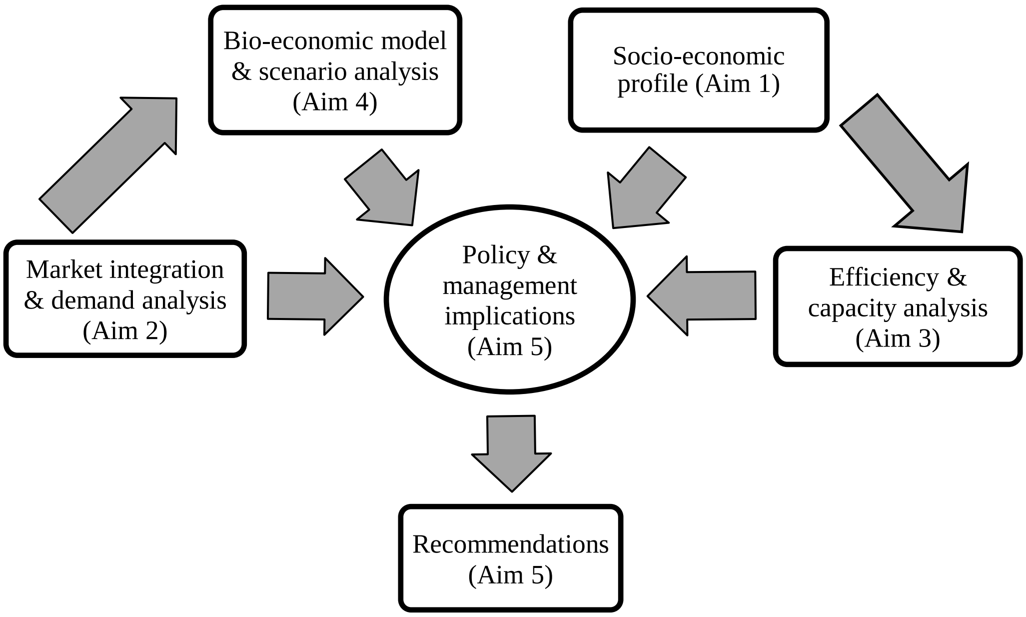
Table 3.1: Tabulated presentation of research aims, benefits, methods and data

Aims	**Aim 1**	**Aim 2**	**Aim 3**	**Aim 4**	**Aim 5**
Description	Develop a socio-economic profile of the SRO industry	Establish the market relationship of the key commercial oyster species in Australia	Determine the level of productive efficiency and capacity utilisation observed for the SRO industry and identify drivers for these observations.	Estimate the simulated impact of climate change and oyster market dynamics on the future economic viability of the SRO industry	Derive focal areas for policy and management consideration that support a sustainable future development of the SRO industry
Importance / Benefit	Identification of socio-economic characteristics of oyster farmers	Identification of potential competitors within one market	Identification of efficient production frontiers and the role of demographic and environmental factors on the observed production efficiency and capacity measures	Assessment of the potential future economic viability of the industry under different climate and market scenarios	Assessment of the need for changes to policies & management, recommendations for economic industry development strategies
Economic method	Farm survey analysis	Market and demand study using cointegration analysis and a demand analysis	Production efficiency & capacity utilisation analysis using the data envelopment estimation technique	Development of a bio-economic model, simulation and analysis of alternative climate and market scenarios	Policy and management analysis which includes an assessment of current polices and industry development plans
Data	Farm survey (primary data set) & industry statistics (secondary data sets)	Time series farm gate data (secondary data set)	Panel data for production, demographic (primary) and environmental variables (secondary data sets)	Panel data including estuary based production and environmental data, climate change predictions (secondary data sets)	Findings from aim 1-4
Integration of analyses	The integration of the economic analyses of the SRO industry aims to gain a comprehensive understanding about the socio-economic characteristics of the industry, the market, the observed production efficiency, potential impact from climate change, the industry management and strategies to enhance the future prospects of the industry.				

Note: PO for Pacific oyster.

The integrated relationship of the different research aims, benefits and methods that were used in the research approach of this thesis is illustrated in Figure 3.1. The demographic data collected in a farm survey were not only employed to develop a socio-economic profile of the industry (aim 1) but also found use in a efficiency and capacity analysis (aim 3), in which the impact of farmer's demographic characteristics on efficiency measures was evaluated. The market integration and demand analysis (aim 2) provided information about the relationship of SROs and Pacific oysters in a market environment. The findings about Australia's oyster market from aim 2 were applied to simulate future bio-economic scenarios for the industry in aim 4.

Figure 3.1: Integration of analysis tools



A detailed description of the economic and statistical analysis tools and their application to available data will be provided in the following chapters. Implications of all individual and combined/integrated findings contributed to a review of the industry's current policies and management strategies (aim 5). This subsequently led to a list of recommendations that may help in supporting the sustainable future development of the SRO industry (aim 5).

3.6 DATA AND ETHICS

The analyses undertaken in the above outlined aims are mostly based on secondary data. The collected secondary data sets include national statistics and industry specific production data that were either publicly available or made available on request by key regulating institutions of the SRO industry. Detailed information on applied secondary data and their sources are described in the following chapters.

A SRO farm survey was conducted for this research program, to gain information about various aspects relevant to oyster production, such as production areas, size of individual farm production, farming practices and stock maintenance, farming inputs and outputs, market information, farmer perceptions of the industry's future and socio-economic characteristics of oyster farmers. This collection of primary data was approved by the QUT Human Research Ethics Committee (approval number: 1200000303). A copy of the survey is provided in Appendix A. While the number of participant's responses to questions about production input, outputs and costs were insufficient for an analysis, the provided information about farmers' personal traits and perception on the industry performance was adequate for statistical analysis. More details about the survey are provided in Chapter 4.

3.7 LIMITATION OF RESEARCH SCOPE

The research presented in this thesis focused on the positive analysis of the SRO industry. A thesis only provides limited scope in respect to time, finances and human resources available to undertake an economic analysis of an entire industry. The range of research topics presented in this thesis was, therefore, incomplete and could have been expanded, *e.g.,* by studying social value of the native oyster species and by investigating farmer behaviour towards production and market risk.

The research presented in this thesis focused on the native SRO industry. In order to gain a comprehensive picture of Australia's edible oyster industry a similar analysis would need to be undertaken for the Pacific oyster industry. A comparison of Australia's key commercial oyster industries could provide a more complete perspective of their competitive relationship. Furthermore, the SRO industry was mostly examined here in isolation from other aquaculture and fisheries industries. There may be issues (*e.g.,* diseases that affect consumer demand) in other aquaculture or fisheries industries that affect the SRO industry; however, an investigation of such effects was beyond the scope of this research.

In addition, philosophical and ethical aspects related to the introduction of an invasive species and the associated biosecurity risk were briefly touched upon throughout the following chapters. However, it was beyond the scope of this thesis to undertake a non-market valuation or multicriteria analysis to assess the benefits and costs of introducing an invasive species. The introduction of such an invasive species to Queensland or NSW may be a management option for the industry, however, this will require additional scientific and economic evaluation not provided here.

Similarly, social aspects related to potential changes in lifestyle of producers and also concerns of other stakeholders (*e.g.,* conservation groups) were not analysed in this thesis, although further discussion on some of these issues were raised as deemed appropriate.

Broader sustainability issues of this aquaculture industry were also not addressed in detail, but were commented on as appropriate.

Lastly, the aim of this dissertation was not to review the appropriateness of the chosen management approach of the industry. We considered the management approach (see Chapter 2.5.5) as suitable for the SRO industry and only focused on a review of selected management strategies and on suggestions for improvements.

3.8 CONTRIBUTION TO KNOWLEDGE

The dissertation used a set of secondary and primary data and established economic methods to analyse the issues of a primary industry in Australia that has received limited economic analysis in the past (except for some basic cost and earnings surveys as explained in Chapter 2). Thus, results generated from this study are novel and enhance the economic knowledge about the SRO industry. This thesis produced the first socio-economic profile of an Australian aquaculture industry; the first model of price formation in the industry, the first analysis of the links between demographic and environmental conditions and production efficiency measures for the industry, and the first bio-economic model of the sector that can be used for policy and management analysis under a range of scenarios.

An additional contribution to academic knowledge has been made by the development of a bio-economic model to simulate potential impacts of climate change and market dynamics on the future revenue of the industry. This model can be adapted to similar industries.

Moreover, at the time of the completion of this thesis the findings of two studies (Chapter 5 and Chapter 6) had been published in peer-reviewed academic journals and two further studies (Chapter 2 and Chapter 4) were in press. A complete list of publications, presentations, interview and award is provided in the front matter of this dissertation.

Furthermore, this thesis has generated new (primary) data that provide a broader picture of the current economic performance of the industry and enables an assessment of its short- and long-term economic viability.

Presently, policies are being based at single species level without consideration of the market interactions – this thesis aimed to demonstrate that these interactions cannot be ignored when setting effective policy in aquaculture. This principle could potentially be expanded to other aquaculture industries in Australia (*e.g.*, prawns that interact on the market with wild caught species as well as imports).

The following Chapter 4 will report the findings from the analysis of the socio-economic profile of the SRO industry which corresponds with aim 1 of the research program.

Chapter 4: Socio-economic industry profile

4.1 INTRODUCTION

Socio-economic characteristics such as age, gender, educational attainment, employment status, and income have been shown to be major factors affecting behaviour of individuals in a wide range of industries, including fisheries and aquaculture (*e.g.*, Pascoe *et al.*, 2014; Tzanatos *et al.*, 2006). These characteristics can shape the development of an industry as well as its response to external drivers, including environmental, economic and policy drivers. Consequently, investigating the socio-economic profile of fishers and aquaculturists can potentially provide important insight into the industry structures and issues, and thus may offer a bases for modifications to the industry management.

The SRO industry has been faced with a range of challenges, particularly since the late 1970s (see Chapter 2). Issues include for example the management of prevailing diseases, water quality impairments from increasing coastal development and increasing market competition from Australia's Pacific oyster industry. This has led to a decline in SRO production value from about 9,250 metric tons in 1980 to 4,500 metric tons in 2012 (NSW DPI, 2013a; Pease & Grinberg, 1995).

It is likely that socio-economic characteristics of industry members have had an influence on the current situation of the SRO industry. However, a longitudinal data survey about the socio-economic profile of the industry has not been undertaken.

The aim of this study was to develop a socio-economic profile of the SRO industry and to illustrate the value of socio-economic information about industry members for an assessment of current industry management strategies. This corresponds with aim 1 of the research program. The following research questions were investigated: Who are SRO growers? Are SRO farmers different from other population cohorts in Australia? What are oyster farmer's perceptions on the status quo and future of the industry? What is the potential role of oyster grower's characteristics in the industry's current economic performance?

The socio-economic profile presented in this study was developed based on data from a SRO industry farm survey which was undertaken in 2012. This study did not only examine demographic and economic characteristics of oyster growers, it also collected information about farmer's opinion about the prospects of the industry and issues that they believe affect the industry's current performance. In the absence of a similar profile for comparable fishery and aquaculture industries in Australia and worldwide, the findings from the survey were compared to other Australian population cohorts where appropriate. The results and their implications for the industry management were discussed. The findings of the study may be of interest for stakeholders of other fisheries and aquaculture industries who are dealing with similar challenges as the SRO industry.

4.2 METHODOLOGY AND DATA

The data for a socio-economic analysis were obtained from an oyster farm survey which we conducted among oyster farmers from Queensland and NSW during July to November 2012. The survey was undertaken as a mail survey. We choose this surveying technique since the industry management advised us that an online survey would not be appropriate for targeted participants due to most oyster farmers' limited IT proficiency.

Mail surveys are known to have a relatively low response rate if potential participants are contacted without any pre-existing awareness of the study (Jobber & O'Reilly, 1996). Therefore, we conducted a meeting with the Queensland oyster farming group in the lead-up to the mailing and distributed information about the survey in an industry newsletters to oyster farmers in NSW prior to conducting the mail survey. A draft of the survey was sent to the industry management and selected oyster farmer representatives for comments on the design and clarity of questions.

The survey was aimed at collecting information about a range of aspects related to oyster production, such as oyster area, farming practices and stock maintenance, farming inputs and outputs, markets, environment, restriction to expansion of production, and personal information about oyster farmers. All data collected referred to the production year 2011/12. A copy of the survey is provided in Appendix A.

Oyster farming in Australia is a regulated activity, thus, it was possible to determine the exact number of permit holders within the industry. In 2012, the SRO industry was comprised of 394 registered farm businesses (permit holders) located in NSW and Queensland. We approached all registered oyster businesses by mailing our survey with the assistance of key State regulatory institutions (see Chapter 2.5.5) which hold confidential contact details of all oyster farmers. A reminder to participate in the study, which included an additional copy of the survey document, was sent out to the oyster farmers two months after the first mailing took place.

Sixteen per cent of all oyster growers responded to the survey. If contact details were provided by the survey participants, a follow-up telephone interview was undertaken in cases where clarification on the responses was required. Responses from 3 oyster farmers in NSW, who were involved in growing Pacific oysters, were eliminated from the analysis as the focus of the study is on the SRO growers only. After digitalising and cleaning of the data, 53 surveys (24 from Queensland and 29 from NSW) representing 13.5 per cent of growers provided an appropriate level of information to develop a socio-economic profile of the industry. It should be highlighted that this distribution of survey responses does not represent the spatial allocation of production volume which is important to be considered in the interpretation of results.

The response to the survey categories oyster area information, farming practices and stock maintenance, farming inputs and outputs provided insufficient information and was inappropriate for any type of economic analysis.

4.3 RESULTS

The results from the survey show that the majority of the surveyed oyster farmers were male (Table 4.1). Only 11 per cent of the oyster growers in the sample were female. The vast majority of the surveyed oyster growers were born in Australia and only 2 per cent in New Zealand.

The median age of oyster farmers in the sample was 56.0 years. Queensland oyster growers appeared to be slightly older than farmers in NSW, with a median age of 56.5 years and 51.5 years, respectively (Table 4.1).

The household composition of all oyster farmers in the sample indicates that there were on average 2.4 people living in their home (see Table 4.1). However, there appears to be a slight difference in the household size between the two States, as Queensland oyster farmers seem to have had less people living in their household than NSW oyster farmers (see Table 4.1). A similar result was found for the number of children of oyster farmers. Queensland growers appeared to have fewer children than NSW farmers.

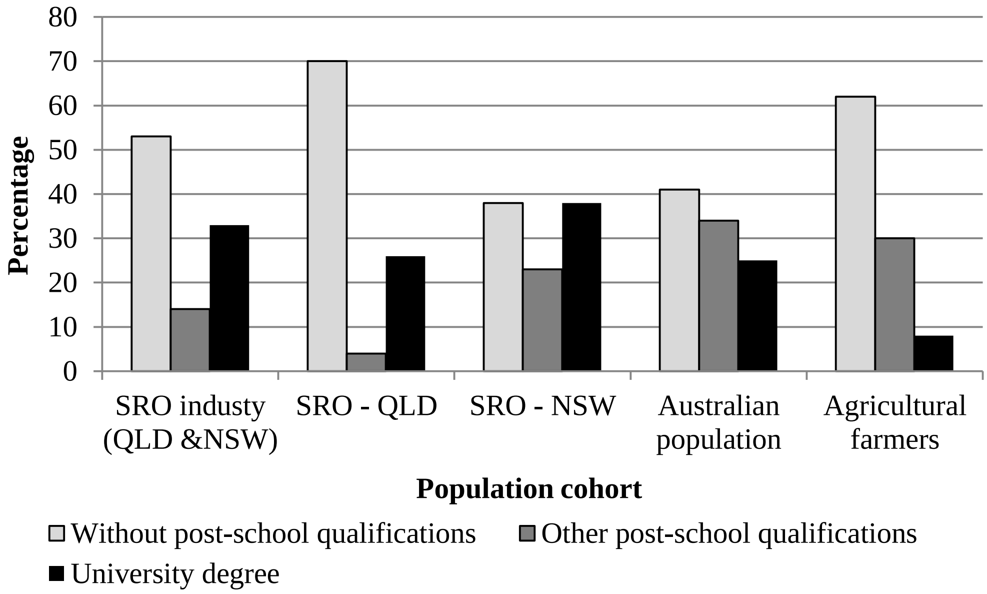
Table 4.1: Demographic information

Demographic characteristics	**QLD**	**NSW**	**TOTAL**
Gender			
Female	16.7%	6.9%	11.3%
Male	83.3%	93.1%	88.7%
Country of birth			
Australia	95.8%	100.0%	98.0%
New Zealand	4.2%	0.0%	2.0%
Other	0.0%	0.0%	0.0%
Age			
Minimum	29.0	25.0	25.0
First quartile	51.0	38.0	49.0
Average	57.5	49.1	54.5
Median	56.5	51.5	56.0
Third quartile	65.0	59.0	62.0
Maximum	76.0	69.0	76.0
Household			
Number of children	2.2	2.5	2.4
Number of people living in household	2.1	2.7	2.4

Figure 4.1 illustrates a summary of the educational attainment of SRO farmers in the sample and other population cohorts. The level of educational achievement within the group of all oyster growers shows that about 53 per cent of farmers had no formal post-school qualifications. About 15 per cent of farmers stated that they obtained a post-school qualification which may include, for example, a vocational training. Approximately 33 per cent of oyster growers reported to have obtained a university degree.

Figure 4.1 also illustrates that growers in Queensland had a slightly lower educational qualification than oyster farmers in NSW. However, the share of farmers who obtained a tertiary degree is for both oyster grower sub-cohorts relatively high with 26 per cent of Queensland and 38 per cent for NSW. The members of the SRO industry appeared to have a similar educational attainment level as the Australian population and a higher educational level than agricultural farmers (Figure 4.1).

Figure 4.1: Educational attainment of SRO industry and other population cohorts

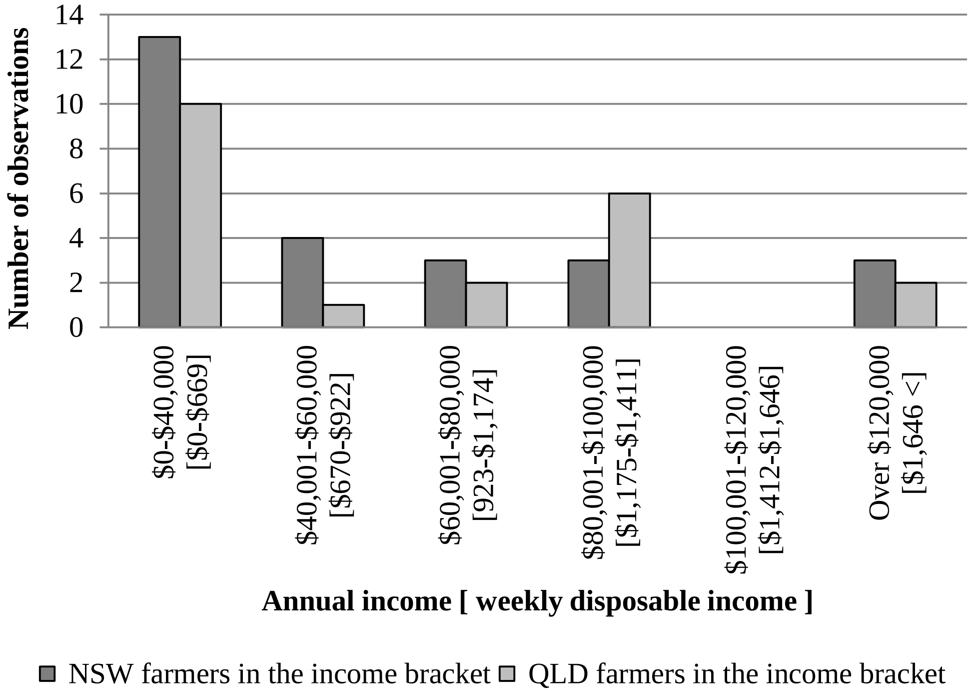


Notes: Without post-school qualification includes 12 or less years of schooling, other post-school qualifications includes 12 years of schooling and additional vocational training (*e.g.*, certificates, diplomas), university degree includes bachelor degrees or post-graduate qualifications. Sources: Australian population statistics (includes people aged 15–64 years) from ABS (2012b), Australian agricultural farmer statistics from ABS (2012a).

A large proportion of the surveyed oyster farmers had a household income of up to 40,000 Australian Dollars per annum (see Figure 4.2). The distribution of household income patterns in Queensland was similar to the one in NSW, although Queensland appeared to have a slightly higher share of household earnings in the 80,000-100,000 Australian Dollars income bracket (Figure 4.2). However, this observation may be attributed to a sampling bias.

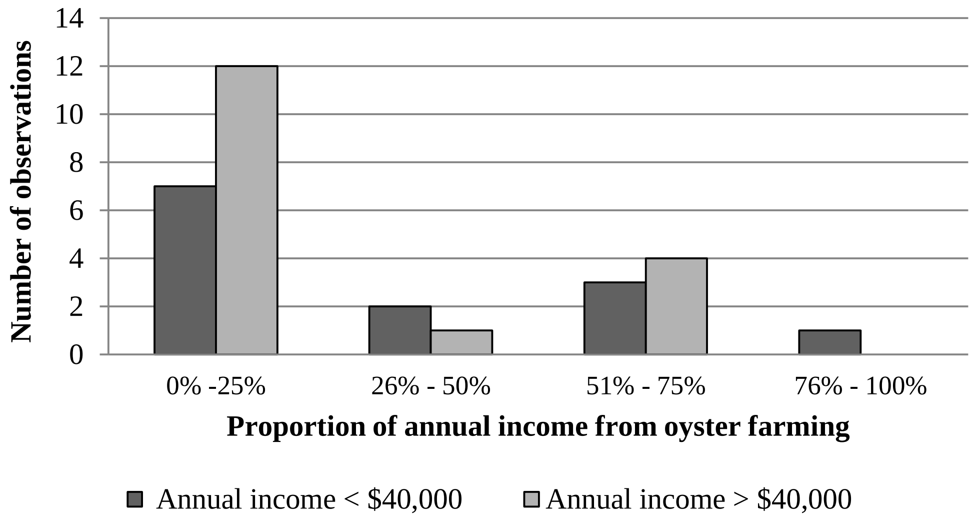
The surveyed oyster growers also reported that a large proportion of their household income is obtained from off-farm activities. The proportion of their total annual income from oyster farming is shown in Figure 4.3.

Figure 4.2: Household income distribution for SRO industry



Notes: All values are in Australian Dollars. Weekly disposable income (net income) estimates for income brackets derived from Australian Taxation Office (2013).

Figure 4.3: Proportion of annual income from oyster farming



Note: All values in Australian Dollars.

A large number of oyster farmers in the sample with an annual income of over 40,000 Australian Dollars received less than 25 per cent of their income from oyster farming. Farmers with an income less than 40,000 Australian Dollar per annum appeared to receive similar proportions of their total income from oyster farming as higher income oyster farmers. While only a small number of farmers in the sample with a total income of up to 40,000 Australian Dollars per annum obtained the majority of their income from oyster farming, no farmers of the higher income brackets seem to have received more than 75 per cent of their annual earnings from oyster farming.

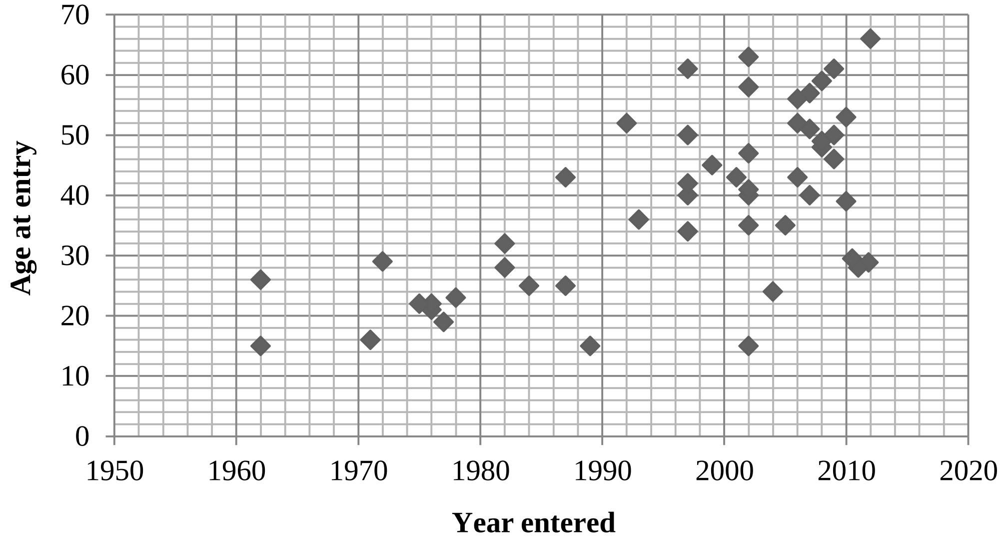
The surveyed SRO oyster growers had on average 15.9 years experience in the industry, ranging from less than 1 year to 50 years (Table 4.2). No experience suggests that survey respondents had entered the industry within 12 months before the survey was conducted. On the other hand, 50 years of experience in the industry implies that some farmers had worked in the industries their entire life. The average level of experience in oyster farming varied between both States, with NSW growers having acquired more expertise in the industry than Queensland growers.

Table 4.2: Experience of oyster farmers

Experience of farmers	**QLD**	**NSW**	**TOTAL**
Years in the industry			
Minimum	0.0	1.0	0.0
First quartile	4.0	6.0	5.0
Mean	14.5	20.2	15.9
Median	10.0	19.0	10.0
Third quartile	28.0	35.0	25.0
Maximum	50.0	50.0	50.0
Inter-generational experience			
Farmers in first family generation in oyster farming	83.3%	60.7%	71.2%
Maximum number of family generations	4.0	6.0	6.0
Association, capacity building, other			
Member in oyster farming association	100.0%	41.4%	67.9%
Attendance of training or workshops in the past year	41.7%	58.6%	50.9%
Experience with other fish / shellfish species	12.5%	27.6%	20.8%

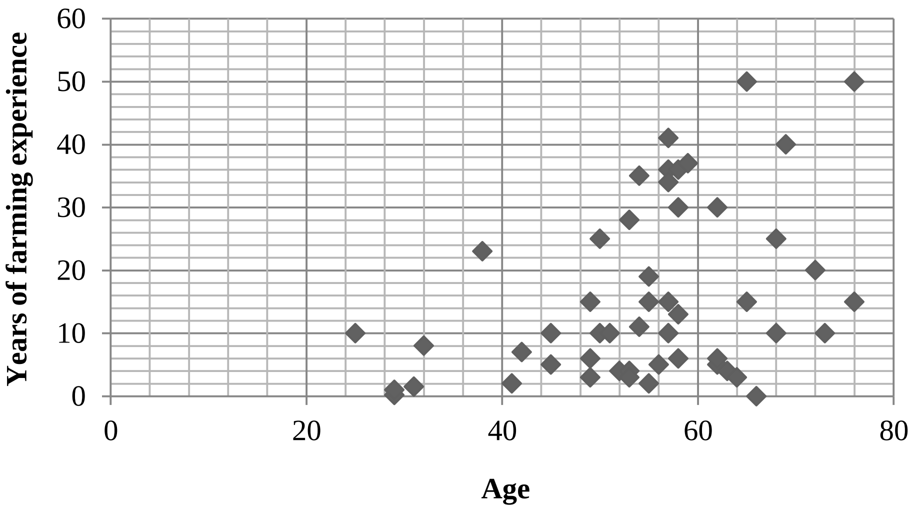
The representation of the results for oyster farmer’s age against the year of entry to the industry in Figure 4.4 shows that most of the current farmers in the sample entered the industry during 1995 to 2010. The illustration also indicates that a large proportion of oyster farmers were at entry to the industry over 40 years of age. The number of farmers entering the industry under the age of 35 in the period between 1960s and 1990s was relative high but decreased in the past two decades.

Figure 4.4: Oyster farmer's age at entry to the industry



The proportion of farmers with less than 15 years of experience in oyster farming was particularly high in the age group of 40 to 60 year old oyster farmers which is illustrated in Figure 4.5.

Figure 4.5: Years of farming experience against farmer's age

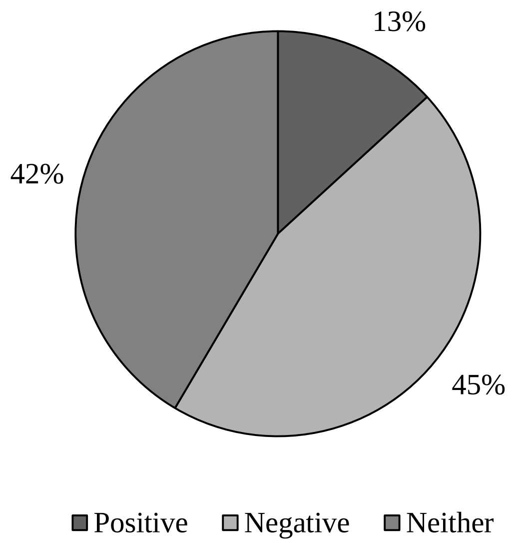


The vast majority of the surveyed oyster farmers were the first generation of oyster growers in their families (Table 4.2). Yet, some businesses were run by the 6th generation of oyster farmers in their family.

About 68 per cent of all oyster growers in the sample were a member in an oyster farming association and about 51 per cent of farmers attended a training or workshop in the past year (Table 4.2). Only 21 per cent of growers had experience in cultivating other fish or shellfish species (Table 4.2).

Survey participants were asked about their perception of the development prospects of the SRO industry. The responses were categorised into positive, negative and neutral attitudes. Although about 42 per cent of responses indicated neither positive nor negative opinions about the future development prospects, almost half of all oyster growers were pessimistic about the industry's future (see Figure 4.6). Farmers with a negative view about the future of the industry clearly outnumbered people with a positive outlook, which was stated by only 13 per cent of participants (see Figure 4.6).

Figure 4.6: Farmer perception on industry prospects



Issues affecting the future development of the industry that were raised included increasing production costs (*e.g.*, fees and charges for water and shellfish sampling and permits), limited product promotion/marketing scope, lack of assistance from government institutions, low product price, competition from the Pacific oyster industry and the very wet weather conditions in NSW in 2011/12 (see Appendix A). On the other hand, some participants identified export of oysters as a potential to expand the industry's current market range and ultimately its profitability. Selected responses from oyster growers about the prospects of the industry can be found in Appendix B.

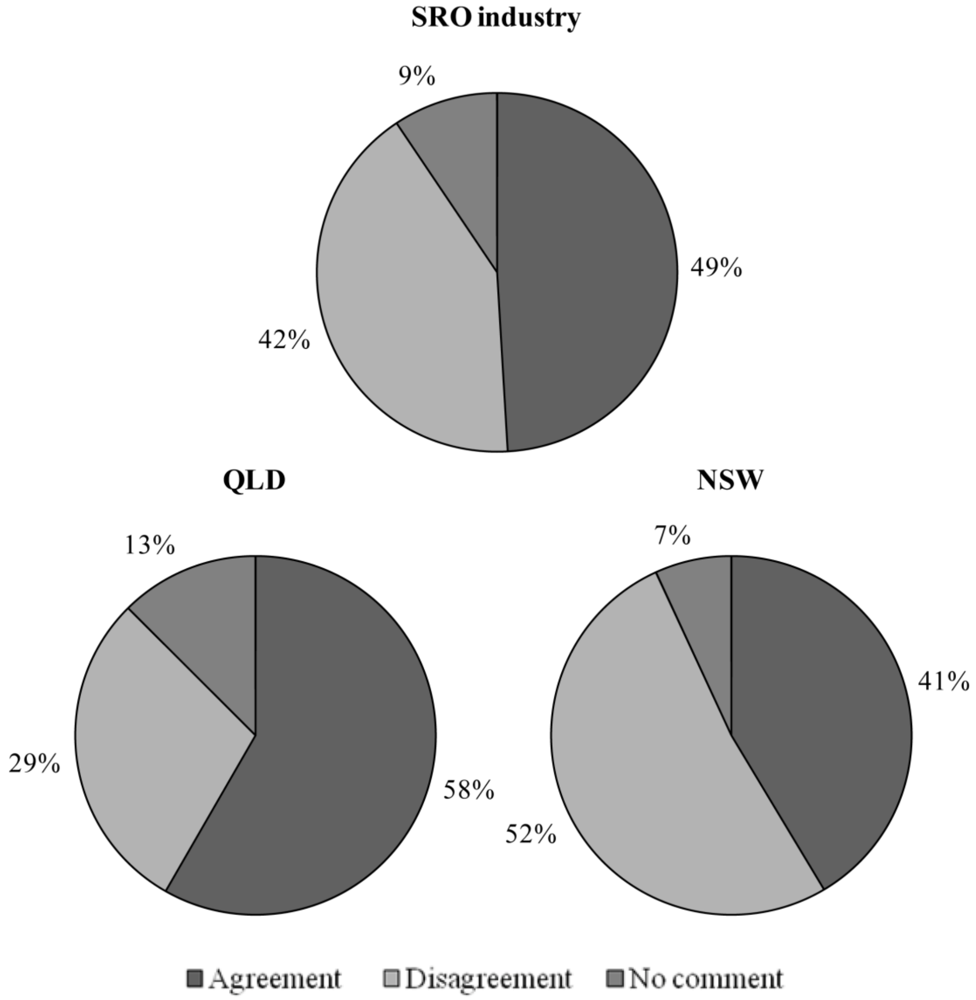
When asked about specific issues that affect the industry, about 68 per cent of all survey respondents agreed or strongly agreed that stock theft is an issue, followed by 65 per cent of participants who indicated that there is a lack of market or that a low product price poses an issue for their business (Table 4.3). Problems with diseases and predators were also identified as major issues with 63 per cent and 64 per cent of respondents agreeing or strongly agreeing, respectively. About half of the farmers in the survey believed that industry bodies are ineffective in supporting oyster farming. Less problematic for industry members appeared to be the availability of oyster areas (27 per cent) and seed (45 per cent) as well as hatchery seed costs (41 per cent). Adequate water quality (35 per cent), the lack of training (17 per cent) and cooperation among farmers (35 per cent) were rated among the least challenging matters for the industry.

Table 4.3: Responses to specific issues of the industry

Issue category	Percentage of responses that rate the category as issue (includes "Agree" and "Strongly Agree")
Availability of seed	45.2
Cost of seed	41.3
Availability of leased land	37.2
Availability of oyster areas	26.8
Lack of markets / low product prices	65.1
Problems with predators	62.8
Problems with diseases	64.3
Inadequate water quality	35.0
Stock theft	68.3
Lack of training	17.1
Lack of cooperation among oyster farmers in the region	35.0
Ineffective bodies to support in supporting oyster farming	54.8
Inappropriate emergency response strategies	43.6

Survey participants were asked to indicate whether they would diversify their current production of SROs by introducing varieties Pacific oysters (wild and/or triploid) if State regulation would permit that. The results show that the industry overall was much divided about the introduction of Pacific oyster varieties. However, Queensland growers appeared to be slightly more in favour of introducing Pacific oysters than NSW growers (see Figure 4.7).

Figure 4.7: Farmer opinion about the introduction of Pacific oysters



4.4 DISCUSSION

The purpose of this study was to develop a socio-economic profile of the SRO industry. The results from the farm survey show that the SRO industry is male dominated which is not untypical for primary industries (Productivity Commission, 2005). The analysis of the survey data revealed that only 11 per cent of SRO farmers were women. This is less than the proportion of women engaged in agricultural farming in Australia (28 per cent) (ABS, 2012a). The very physical work involved in oyster farming is a likely reason why the majority of oyster farmers are male. The relatively low number of female oyster growers in this industry could also be culturally motivated. However, several survey respondents mentioned in follow-up phone interviews that their wives are engaged to some degree in the oyster business, *e.g.*, accounting or other part-time paid or unpaid farm support work.

The majority of SRO farmer's country of origin is Australia. This suggests that the cultural and ethnical background of oyster farmers is less diverse than the rest of Australia's population (about 30 per cent of Australia's population was born overseas) (ABS, 2013a). The commonly used marketing slogan 'Australian owned' can incontestably be applied to goods offered by this industry.

The findings from our survey also show that the SRO industry is dealing with an aging farmer population. A similar trend has been observed for Australian agricultural farmers (ABS, 2012a; Productivity Commission, 2005). Yet, oyster farmers are likely even older than agricultural farmers in Australia. While the median age of agricultural farmers was 53 in 2011 (ABS, 2012a), SRO oyster farmer's median age exceeded that age by three years (Table 4.1). Furthermore, oyster farmers are also considerably older than workers in other professions in Australia, whose median age was 40 years in 2011 (ABS, 2012a).

Farmers in NSW are likely to have slightly more children than Queensland oyster farmers. The oyster growers in Queensland are more likely to live in smaller households than NSW growers. The slightly lower median age of NSW growers and their larger household size compared to Queensland growers suggests that children may still be part of their households.

SRO farmers show on average a similar level of educational qualification compared to Australia's total population (ABS, 2012b) and a higher educational level than Australia's agricultural farmers (ABS, 2012a) (see Figure 4.1). Given that the combined proportion of farmers with post-school and tertiary degrees is higher in NSW than in Queensland, NSW growers are likely to have a higher educational level than Queensland growers. The farmers in NSW may have obtained a higher level of academic qualification than Australia's total population. However, this finding may be likely due to a sampling bias and should be interpreted with caution.

The very high proportion of growers without post-school qualifications in Queensland may be explained by the older age of farmers in this production region. The proportion of individuals without post-school qualifications is currently lower in higher age groups in Australia (ABS, 2012b) and most likely reflects a lack of access to further educational training for these age groups, historically. Another likely reason for the higher degree of qualification amongst NSW farmers compared to their counterparts in Queensland may be linked to the differing scale of production in these regions, which is generally higher in NSW than in Queensland. With increasing production scale, aquaculture farm businesses are becoming increasingly complex. Thus, large-scale oyster farmers may need to be more educated than traditional farmers and more qualified as managers with the same skill and responsibility as any business managers (based on Cary, Webb & Barr (2002)).

The majority of oyster farmers reported a disposable income of less than 669 Australian Dollars per week (or up to 40,000 Australian Dollars annually) (see Figure 4.2). Compared to income statistics for all Australian households most oyster grower can be categorised as low income households[14]. Comparable Australian population cohorts in terms of age appear to have a higher weekly disposable income than the majority of oyster farmers. For example, in 2011-12 a couple (older than 35 and younger than 55) with dependent children (aged between 15 – 24 years) had a mean household income of 873 Australian Dollars per week and a couple aged 55 to 64 years with no children received a mean disposable income of 1,044 Australian Dollars per week (ABS, 2013c). Furthermore, the mean disposable household income of all households in Australia in 2011-12 was 918 Australian Dollars per week (ABS, 2013c), which is higher than the weekly income of oyster farmers. In contrast to that, the weekly income of Australian agricultural farmers was 568 Australian Dollars during the same period which is lower than what we found for oyster growers (ABS, 2012a)[15]. It can be concluded that oyster farmers and agricultural farmer belong to the same low household income category as defined by the Australian Bureau of Statistics (ABS, 2013c).

The study further found that a low proportion of the farmer’s household income is generated by their oyster business (Figure 4.3). This suggests that SRO farming is a part-time activity for a large proportion of farmers and that household income of most people engaged in SRO farming is obtained from other income generating activities. This finding supports industry statistics showing that SRO

[14] Lowest threshold for weekly disposable income of low income households: 475 Australian Dollars; lowest threshold for weekly disposable income of middle income households: 793 Australian Dollars; lowest threshold for weekly disposable income of high income households: 1,814 Australian Dollars (ABS, 2013c).
[15] We only report the upper threshold of weekly disposable income while Australia agricultural farmer income statistic displays an average value.

industry is dominated by small-scale business (NSW DPI, 2013a). Unfortunately, our survey did not explore the nature of off-farm activities in further detail.

Although the survey asked participants about production volume, income, costs, and farm assets and their value, the number and quantity of responses to these questions were insufficient for an analysis. Hence, an investigation into accounting balances, profitability and structure of assets and liabilities of SRO farming businesses such as undertaken by Girard *et al.* (2014) for oyster farming enterprises of Marennes-Orleron Bay in France could not be undertaken.

Since oyster farmers mostly own and manage their businesses it would be difficult to analyse their personal financial circumstances in isolation from the financial arrangements of their oyster farm and other income sources. Losses from farm income are commonly deferred over subsequent production years and profits are often reinvested into the business. Oyster farmers and agricultural farmers are very similar in that regard (ABS, 2012a). While oyster farmers may have a low income, it needs to be emphasised that disposable income is only one aspect of farmer's economic well-being. Wealth in form of superannuation, property, shares, and oyster farm assets may be drawn upon to smooth and support household consumption over time, particularly in periods of very low income from oyster farming. Other aspects of economic well-being may include motivation (*e.g.*, way of life, to have independence at work, having greater flexibility for personal/family life, having the power to make own business decisions) and opportunity costs of oyster farmers to work in this primary industry. These aspects could be of importance in order to attract new people to become oyster growers.

Our observation that a large proportion of farmers who entered the industry in the last 20 years were of mature age (Figure 4.4) suggests that a relatively high number of individuals worked in different professions and chose to become an oyster farmer at pre-retirement age based on life-style decisions. This finding may be supported by the relatively high proportion of farmers with tertiary qualifications that are required in other professions.

Interestingly, the majority of oyster growers appear to be first generation oyster farmers (see Table 4.2). This indicates that the skill of oyster farming is mainly an acquired skill (at mature age) that is not handed down among family generations. This is particularly the case for Queensland where over 80 per cent of growers are first generation oyster farmers.

Of particular concern are the very low proportion of young farmers present in the industry and the high proportion of oyster growers older than the official retirement age in Australia (Table 4.1). This together with the trend towards fewer young people entering the industry (see Figure 4.5) may be attributed to increasing well-paid employment alternatives in other industries, such as the mining industry during the past 15 years. A similar trend was observed in Australian agricultural farming were the proportion of farmers aged less than 35 years fell from 28 per cent in 1981 to 13 per cent in 2011 (ABS, 2012a). Another reason that may prevent young people to enter the industry may be the lack of access to capital since financial institutions are generally reluctant to loan against oyster leases due to the high production risks involved. Other factors that may contribute to the skewed age profile of oyster farmers may include: a) fewer people in total entering the oyster industry; b) low exit rate at traditional retirement age, due to relatively late entry, and possibly compounded by limited interest of young people in taking over the oyster farms; c) delayed industry exit decisions in response to reduced farm capital during poor seasons or reduced market value during periods of low market prices (based on Productivity Commission (2005)). A more detailed analysis is required to identify potential industry entry barriers and to attract and facilitate the entry of more young people to the industry. The industry is located in rural coast regions where unemployment is higher than in metropolitan regions of Australia (ABS, 2013d), thus, options of drawing on this employment situation should be investigated by the industry management.

The present age structure of the industry members, the predominantly small-scale and part-time business approach to oyster farming raises a concern about implications for innovation and the attraction of investment. A previous study about primary industries in Australia concluded that the main limitations to the adoption of new technologies were human capital and knowledge constraints, with farmers not having the necessary skills, incentives or information required for successfully integrating innovations into existing farming systems (Nossal & Sheng, 2010). Similar to other primary industries, the SRO industry will remain depended on public investment in research and development irrespective of the age structure of oyster farmers. However, the ability to drive/support the innovation and their translations into industry practise as well as willingness to co-operate with research institutions may improve with more young people entering the business.

The important role of producer organisations in fishery industries has recently been investigated by Karadzic *et al.* (2013). These authors found that fishers perceive and understand their membership experience as important to their capacity to learn from each other. It was also shown that producer organisations affect attitudes towards adaption to change in practice, economic and other incentives (*e.g.,* need to belong), rules and trust in leadership (Karadzic *et al.* 2013). The results from this study show that almost 70 per cent of all oyster farmers in the survey were members in a farming association (see Table 4.2). These institutions, mainly NSW Farmers and Queensland Oyster Grower Association, provide a representation of the industry, consultation, sharing of information, training and advocacy. The proportion of oyster farmers affiliated with a farming organisation was highest in Queensland. This is likely due to the limited spatial distribution of oyster farming in Queensland, which is mostly located in or around the Moreton Bay and may offer more opportunity for association. Based on the findings, it can be assumed that social learning, collaboration and collective action within the SRO oyster farmer community is reasonable high.

The responses from survey participants suggested that SRO industry members have a rather pessimistic view about the prospects of the industry (Figure 4.6). Frustration comes from the decreasing profitability of their businesses due to low product prices and increasing production cost (*e.g.,* food safety compliance costs). Furthermore, increasing severe weather events also appear to cause increasing negative attitudes among farmers. Nevertheless, we also found that farmers are very fond of their products (see Appendix B, *e.g.,* Part-42, Part-44, Part-46).

The sensitive matter of a potential further expansion of areas allocated to wild and triploid Pacific oysters cultivation in NSW and Queensland was reflected in the responses of the farmers (see Figure 4.7 and Appendix B). The industry is clearly much divided about this topic which reflects the difficulty for the industry management to respond to economic losses in the SRO industry by employing alternative oyster industry management strategies. A decision to expand areas allocated to wild and triploid Pacific oyster cultivation in NSW and to Queensland should be underpinned by scientific and economic research, which allows a full valuation of possible economic, social and environmental trade-offs.

This study was, to the knowledge of the authors, the first survey-based investigation into socio-economic situation of the SRO industry. It should be noted, however, that gaps in responses to several sections of the survey limited the array of assessed characteristics. For example, we asked participants about labour input on oyster farms but the number of responses was inappropriate for an analysis. Furthermore, the obtained sample size of 53 oyster farmers is relatively small and may not appropriately reflect all properties of the entire oyster farmer population. Thus, results may be biased. Future surveys on the socio-economic characteristics of farmers should also include questions about farmers' perceptions about industry entry barriers, potential opportunity costs of being an oyster farmer and types of off-farm activities. Due to the lack of time series data an analysis of possible changes in the profile of SRO farmers could also not be undertaken.

4.5 CONCLUSION

The aim for this study was to develop a socio-economic profile of the SRO industry. A descriptive approach to analyse data from an oyster survey was chosen to generate primary information about SRO farmers.

The findings of this study suggest that the majority of SRO growers are male, Australian born and the first generation in their family in oyster farming. A large number of farmers in this industry are of pre-retirement or retirement age. This suggests that oyster farmers have likely gained experience in different professions before becoming an oyster farmer. This finding is supported by the relatively high proportion of current oyster farmers with tertiary qualifications. The relatively low proportion of income generated from oyster farming implies that oyster farming may not be a full-time activity for the majority of growers. This also endorses previous industry statistics that this industry is dominated by small-scale businesses. The aging farmer population and the low number of young oyster growers present in the industry raises the question about potential industry entry barriers. It is unclear why the industry appears to be unappealing for young people. Possible reasons may be the demanding physical work and the relatively low return from oyster production. Other explanations may be the presence of alternative employment offered in other industries or a lack of access to capital. Given the lack of information about young oyster farmers, the industry needs to investigate their profile, motivations and issues further as prerequisite to attracting people to the industry.

Given the current age structure, as well as the part-time approach to oyster farming, the ability of SRO growers to drive and support innovation and their translations into industry practice, as well as willingness to co-operate with research institutions may be compromised. This may hamper future industry development.

The study also provides evidence that oyster farmers have a relatively pessimistic opinion about the future of the industry and that growers are much divided about the introduction of Pacific oyster varieties in NSW and Queensland.

In summary, the findings of the study suggest that socio-economic characteristics of the SRO growers may contribute to the current decline in SRO production. The future development of this industry will therefore also depend on the ability of the industry management to address the socio-economic issues present in this industry.

The following Chapter 5 focuses on a market and demand analysis of Australia's main commercial oyster species in order to assess whether market dynamics affected the economic viability of the SRO industry.

Chapter 5: Market and demand analysis of Australia's main commercial oyster species

5.1 INTRODUCTION

Economic competition between introduced and native aquaculture species is of interest for industry stakeholders since increased production can affect price formation if both aquaculture species are part of the same market or even substitutes. A wide range of studies investigated the impact of aquaculture products on markets for seafood (*e.g.*, Gordon *et al.* (1993), Jaffry *et al.* (2000), Bjørndal (2002), Asche *et al.* (2004), Jiménez-Toribio *et al.* (2007), Norman-López and Bjørndal (2009)). Previous studies confirm that market interaction is greatest for 'similar' products (Asche *et al.*, 2001; Jiménez-Toribio *et al.*, 2007). The existence of a long-run price relationship between goods can have significant implications for the development of an industry that consists of different market segments, *e.g.*, although one segment may increase its production, the other may lose in its market share (Jiménez-Toribio *et al.*, 2007). However, competition may also have positive effects. For example, the existence of a larger market for aquaculture products, that are treated as similar goods, may assist the growth and promotion of all market segments compared to products with few or no substitutes (Asche *et al.*, 2001). Moreover, as individual aquaculture products evolve and mature, markets that comprise new species become more established as consumer preferences for fish may become more complex in their interactions (Asche *et al.*, 2001).

In this study we focused on the two key species in Australia's predominantly domestic oyster market which are the native SRO and the non-native Pacific oyster, which together account for about 95 per cent of total edible oyster production (Love & Langenkamp, 2003).

The SRO is endemic to south-east Queensland and NSW, and has been introduced into parts of Western Australia. The Pacific oyster is cultivated mainly in TAS and SA where it was introduced in the 1950s and 1960s respectively (Mitchell *et al.*, 2000; PIRSA, 2003), although sterile varieties (triploids) are increasingly grown in NSW (see Chapter 2.4.5). The Pacific oyster's invasive behaviour of native habitats (Medcof & Wolf, 1975; Pollard & Hutchings, 1990) requires a strict regulatory separation of the two species growing areas.

Australia's edible oyster industry contributes about 100 million Australian Dollars to the national gross domestic product annually and is the fourth largest aquaculture sector after salmon, tuna and pearls (ABARES, 2010). The total production of edible oysters has increased from about 8,100 metric tons in 1988-89 to 13,911 metric tons in 2011 (ABARE, 1991; ABARES, 2012) nearly all of which (98 per cent) is consumed in the domestic market. This growth in production was driven by an expanding production of Pacific oysters in SA while the production of the SRO has slightly decreased over time (ABARE, 1991; ABARES, 2012). The development of the Pacific oyster industry may have contributed to this decline in production of SROs through its impact on price (see Chapter 2.4.5).

The aim of this study was to examine the integration of the Australian oyster market and to determine whether the market treats the two oyster species as one or separate products. This corresponds with aim 2 of the research program. By testing the existence of the Law of One Price (LOP) it can be established whether goods have the same price and thus are treated by the market as identical. We used the Johansen cointegration technique (Johansen, 1988) and the autoregressive distributed lag (ARDL) bounds testing approach (Pesaran *et al.*, 2001) to identify any relationships in the available farm gate level price time series data.

Furthermore, we estimated the short- and long- run own- and cross-price flexibilities of the two key commercial oyster species using an inverse demand model, which is more appropriate for perishable goods with inelastic short-run supply such as edible oysters (*e.g.*, Barten and Bettendort (1989)). This approach assumes that the price of edible oysters is a function of the quantities supplied.

5.2 DATA

For our analysis, we primarily used annual farm gate data for the period 1989-2011 which was collected by the Australian Bureau of Agriculture and Resource Economics and Science (ABARES) and published in the annual Australian fisheries statistics (ABARE-BRS, 2010; ABARE, 1991, 1993, 1994, 1995, 1996, 1997, 1999, 2000, 2001, 2002, 2003b, 2004, 2005, 2006, 2007, 2008, 2009; ABARES, 2011, 2012). These data were supplemented with production and value data from Queensland (Lobegeiger & Wingfield, 2006, 2007, 2008, 2009, 2010) and NSW (NSW DPI, 2010). Producer organisations in both Tasmania and South Australia were also contacted, and were able to correct some apparent errors in the production and price series derived. Since quantities produced in Queensland were reported in units of dozens and the ABARES series accounts in tons, we undertook a conversion of units. The conversion rate from dozen to tons was 0.000633, which we obtained by averaging the ratio of overlapping observations in both series. The final data sets contained 23 annual observations for each oyster producing State covering the period 1989 to 2011. Earlier oyster production records were not consistently available for all States, with only Queensland having earlier records. A summary of the data used in the analysis is given in Table 5.1. For the analysis, all data were logged.

Table 5.1: Descriptive statistic of data used in the analysis

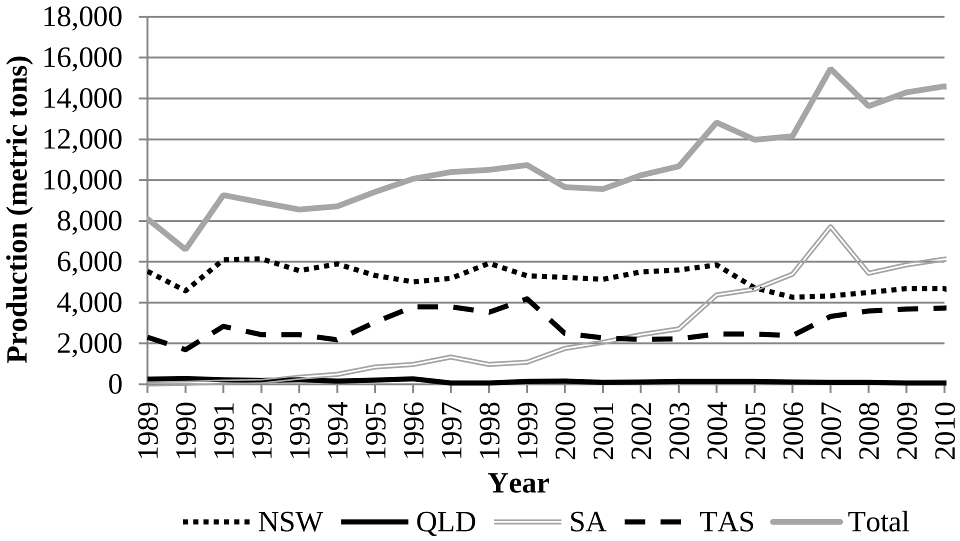
	Mean	**Std. dev.**	**Minimum**	**Maximum**
Real prices ($/kg)				
NSW	9.23	0.91	7.88	11.58
QLD	7.48	1.05	5.26	9.69
TAS	7.68	1.16	5.58	9.13
SA	7.21	1.45	5.35	11.70
Quantities (kt)				
NSW	5.23	0.57	4.27	6.14
QLD	0.15	0.07	0.06	0.28
TAS	2.87	0.71	0.02	7.72
SA	2.49	2.40	1.69	4.19
Real income ($/month)	970.38	26.09	932.95	1,021.23

Note: kg for kilogram, kt for kilotons, $ for values in Australian Dollars.

The ABARES, NSW and Queensland data included annual production quantities and values of other oyster species farmed in each State. However, these quantities comprised less than 5 per cent of the total production in each of the examined States and were therefore ignored (Lobegeiger & Wingfield, 2006, 2007, 2008, 2009, 2010). For the purposes of the analysis, Queensland and NSW were assumed to only produce SROs and Tasmania and South Australia produce only Pacific oysters. The small quantities of SROs produced in Western Australia were also not considered.

Prices were derived by dividing the production value by the quantity produced, and converted to real values using the Australian consumer price index (ABS, 2013b) with 2011-12 as the base. Real prices generally decreased over the period of the data (see Figure 5.2), consistent with the increase in supply to the domestic market (see Figure 5.1).

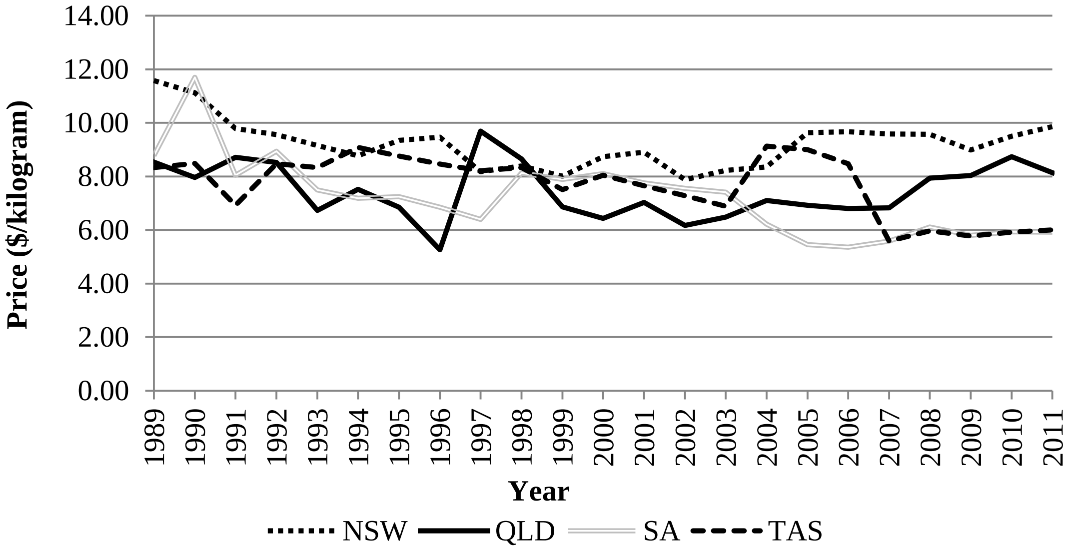
Figure 5.1: Edible oyster production in Australia, 1989-2011



Note: Approximately 62.5 kilogram equals 1 bag of SROs. Source: ABARE (1991, 1993, 1994, 1995, 1996, 1997, 1999, 2000, 2001, 2002, 2003b, 2004, 2005, 2006, 2007, 2008, 2009), ABARE-BRS (2010), ABARES (2011, 2012).

Since we used annual prices for the analysis, seasonal price effects could not be observed for the farm gate level production. Any product differentiation effects of prices such as the sale of oysters in three different grades were also ignored due to the lack of sufficient data.

Figure 5.2: Evolution of real prices over the period of the data



Source: ABARE (1991, 1993, 1994, 1995, 1996, 1997, 1999, 2000, 2001, 2002, 2003b, 2004, 2005, 2006, 2007, 2008, 2009), ABARE-BRS (2010), ABARES (2011, 2012).

Information on average monthly household earnings was available from the Australian Bureau of Statistics (ABS, 2008, 2011). While data were available at the State level, for the Pacific oysters (and to a much less extent for the SROs) the exact final destinations of the product was not known. Consequently, the national average household earnings was applied to all States.

5.3 METHODS

The analysis was undertaken in two main stages. First, market delineation analysis was undertaken in order to determine how many markets exist. The second stage involved estimation of the oyster demand function.

5.3.1 Market integration analysis

Cointegration analysis to examine price interdependencies and market delineation has been applied in a wide variety of studies relating to farmed and wild caught fish and fish products (Asche *et al.*, 1999; Asche *et al.*, 2004; Asche *et al.*, 2007; Asche & Salvanes, 1997; DeVoretz & Salvanes, 1993; Jaffry *et al.*, 2000; Nielsen, 2005; Nielsen *et al.*, 2009; Norman-López & Bjørndal, 2009). A prerequisite for the test of cointegration is to verify that the price series are non-stationary and to determine the variables' integration order. We use the Augmented Dickey Fuller (ADF) unit root test (Dickey & Fuller, 1979, 1981; Said & Dickey,

1984) to assess the stationary characteristic of each price series. The ADF test captures autocorrelation in the disturbance term, and by including lagged values, the ADF formulation allows for testing higher order autoregressive processes (Dickey & Fuller, 1981). However, the relatively small number of observations in the data series necessitates a limited selection of lags in order to avoid a further distortion in the power (Ng & Perron, 1995). We applied Schwert's rule for determining the optimal lag length (Schwert, 1989), which suggested a length of 1 lag was appropriate given the frequency and quantity of data.

Cointegration between the prices in different locations or products could arise if price differentials between the locations/products were stationary. Thus, if two price series that are non-stationary in their unit roots are linearly combined and exhibit stationary properties in their residuals, it can be concluded that the markets of the two price series are cointegrated.

We use the Johansen test (1988) to explore the long-run relationship between prices from the oyster producing States. The Johansen test is a well established and widely applied method to identify conintegration relationships between time series variables that are stationary in their differences (*e.g.*, Norman-López & Bjørndal, 2009; Norman-López *et al.*, 2014). The Johansen test is considered to be an advanced method to other techniques, such as the Engle-Granger cointegration test, as it allows the test of multiple times series simultaneously. However, it is subject to asymptotic properties of the sample.

The Johansen test is based on an unrestricted vector autoregressive (VAR) system in the levels of the variables and can be represented as following:

$$P_t = \prod_1 P_{t-1} + \ldots + \prod_k X P_{t-k} + \mu + \epsilon_t \tag{5.1}$$

where P_t denotes a n × 1 vector of prices and each of the Π_i is an n × n matrix of parameters, μ is a constant term and ϵ_t as identically and independently distributed residuals. While this VAR model is a general framework to describe the relationship among stationary variables in their levels, the vector error correction (VEC) form is a special case of the VAR model for variables that are stationary in their differences (I(1)). The vector VAR model in its error correction form can be expressed as:

$$\Delta P_t = \Gamma_1 \Delta P_{t-1} + \dots + \Gamma_{k-1} \Delta P_{t-k+1} + \Pi P_{t-k} + \mu + \epsilon_t \quad (5.2)$$

with $\Gamma_i = -(I - \Pi_1 - \dots - \Pi_i)$, i = 1, ...,k-1, and $\Pi = -(I - \Pi_1 - \dots - \Pi_k)$.

The Johansen test focuses on the examination of the Π matrix with Π_k as the long-run level equilibrium to equation (5.1). Moreover, matrix $\Pi = \alpha\beta'$, where α represents the speed of adjustment and β the matrix of long-run coefficients or the error correcting mechanism.

The Johansen technique suggests two asymptotically equivalent tests for cointegration analysis, the maximum eigenvalue test and the trace test. In our study, we focus on the trace test. The test for cointegration between the P_t is calculated by looking at the rank, *r*, of matrix Π_k which determines how many linear combinations of P_t are stationary. The null hypothesis of the trace test is that there are, at most, *r* cointegration vectors. The variables in levels are stationary if r = n. None of the linear combinations are stationary if r = 0, then Π = 0. However, if 0 < r < n, r cointegration vectors exist.

Furthermore, we test for the LOP on variables that are found to have an equilibrium relationship. This allows us to determine the degree to which the goods are perfect or imperfect substitutes. The LOP can be tested by imposing the restriction β' = (1,-1)'.

To determine any long-run relationship between the prices in the oyster producing States we tested for market integration between two price series at a time. Since the available price data series only contain 23 observations, we consider the lag length chosen by the Schwarz information criterion (SIC) of optimal order to investigate the existence of a long-run relationship. Consequently, we are unable to examine any short-run relationships and causal relationship between the prices using the Johansen test approach.

The Johansen test focuses on cases in which the underlying variables are integrated of order one, which involves unit root pretesting and, thus, involves a further degree of uncertainty into the analysis of level relationships (Pesaran *et al.*, 2001). Given that additional degree of uncertainty when using the Johansen test and the use of a relatively short time series we employed the bounds testing approach to analyse level relationships in time series data as described by Pesaran *et al.* (2001). The bounds testing approach is here used to verify the findings of the Johansen test by examining the existence of a relationship between variables in levels which is applicable irrespective of whether the underlying regressors are purely I(0) (no cointegration), purely I(1) (cointegration) or mutually integrated (Pesaran *et al.*, 2001). To implement the bounds testing procedure we employ a conditional ARDL model as follows:

$$\Delta P_1 = \alpha + \beta t + \gamma_1 P_{1,t-1} + \gamma_2 P_{2,t-1} + \sum_{i=1}^{m} \delta_1 \Delta P_{1,t-i} + \sum_{i=1}^{m} \delta_2 \Delta P_{2,t-i} + \epsilon \quad (5.3)$$

The order, *m*, of the vector autoregressive lag in this model is determined by the SIC as shown in Table 5.3.

The bounds test for examining possible long-run relationship among prices can be conducted using the Wald or F-test statistic to test the significance of lagged level of the price variables under consideration of a conditional unrestricted equilibrium correction model. We test for the null hypothesis that there exists no relationship in the levels between the price variables, irrespective of whether the regressors are purely I(0), purely I(1) or mutually cointegrated. Two sets of critical values are provided in Table 5.5 for the two polar cases which assume that all regressors are either purely I(1) or purely (0). If the computed F-statistic falls outside the critical value bounds, a conclusive inference can be derived without knowing the integration/cointegration status of the underlying regressors (Pesaran *et al.*, 2001). However, if the F-statistic falls inside these critical bounds, inference is inconclusive and knowledge about the integration of the underlying variables is required before a conclusive inference can be made (Pesaran *et al.*, 2001). We are testing the bounds for a model with no intercept and no trend ($\alpha = 0$ and $\beta = 0$) and for a model with an unrestricted intercept and no trend (α = unrestricted and $\beta = 0$). The critical bounds for the case of no intercept and no trend were derived from Pesaran *et al*. (2001) and for the case of an unrestricted intercept and no trend critical values were taken from Narayan (2005).

The ARDL bounds testing approach to cointegration of prices allows us to identify price leadership among the series. This is the case when the null hypothesis of no cointegration cannot be accepted for the dependent variable.

5.3.2 Demand analysis

Lack of market integration does not preclude the possibility that the supply of one species can have an impact on the price of the other. The estimation of the own- and cross-product flexibilities of demand provides not only insight about the demand-supply relationship for oysters in each market, but also allows us to determine whether the market treats the two oyster species as substitutes or not. Inverse demand models essentially assume that the market price adjusts to clear the (exogenous) supply, and effectively represent the average revenue function. Given the production lag between the initial production decision and the time of harvest, and the highly perishable nature of the product, an assumption that supply is exogenously determined (at least relative to the current price) is realistic.[16] Quantities supplied to the oyster markets are relatively fixed and determined by the seeded stock, the growth period (18 months to 3 years depending on species and grade), and risks affecting the harvestable stock. Inverse demand models have been applied to fisheries products in many other studies (Asche, 1997; Barten & Bettendorf, 1989; Bose & McIlgrom, 1996; Burton, 1992; Eales *et al.*, 1997; Jaffry *et al.*, 1999; Pascoe & Revill, 2004), as well as studies of oyster demand elsewhere (Dedah *et al.*, 2011; Lee & Kennedy, 2008).

Non-stationarity in prices and quantities indicate dynamics in the demand relationship, and hence prices cannot be modelled directly as a function of the quantity supplied in that period. Instead, initial changes in price with quantity change may be greater or less than the longer term "equilibrium" price given that quantity level. Previous studies of demand in fisheries have captured these dynamic effects through the use of vector error correction models incorporating Johansen's (1988) procedure to estimate long-run effects directly (Jaffry *et al.*, 1999) or error correction models that capture both short- and long-run effects (Pascoe & Revill, 2004). In this study, the latter approach was undertaken.

The basic form of the error correction model can be expressed as:

[16] Preliminary models of supply suggest that the quantity of SRO produced in any one year is a function of the prices of Pacific oysters two and three years earlier. As Pacific oyster are still a developing industry, no meaningful supply relationship between price and quantity produced can be established.

$$\Delta p_{k,t} = \propto + \sum_{k=1}^{K} \beta_k \, \Delta q_{k,t} + \sum_{j=1}^{(n-1)} \gamma_k \, \Delta p_{k,t-j} + \sum_{k=1}^{K} \sum_{j=1}^{(n-1)} \delta_k \, \Delta q_{k,t-j} + \lambda_k p_{k,t-n}$$

$$+ \sum_{k=1}^{K} \mu_k \, q_{k,t-n} + \varphi \Delta inc_t + \sum_{j=1}^{(n-1)} \tau \Delta inc_{t-j} + \omega inc_{t-n} + \varepsilon_{k,t} \quad (5.4)$$

where $\Delta p_{k,t}$ as the change in the price of product k in period t, $\Delta q_{i,t}$ is the change in the quantity, *inc* is the average monthly household income, and n is the number of lags over which the dynamic processes are being assessed. Prices, quantities and income are in natural logarithms and ε is the error term.

We can interpret the estimated coefficients for β_k as the short-run price flexibilities, while the ratio $-\lambda_k / \mu_k$ gives the lon-run own- and cross-price flexibilities. The derived sign of the cross-price flexibilities indicate whether the two oyster species are treated as substitutes or complements.

5.4 RESULTS

5.4.1 Market integration analysis

The first stage of the analysis involved testing for stationarity in the price and quantity series, and cointegration between the price series. Using the ADF test, the null hypothesis is that the series are non-stationary. The series is integrated of order one (*i.e.*, I(1)) if the non-stationary series in levels can be rendered stationary by first differencing. For the stationarity tests, several alternative forms of the ADF test were estimated involving various combinations of trends and/or constants or neither trend nor constant. For NSW and QLD, the most appropriate model included an intercept and a trend, while for TAS and SA only an intercept was found to be the best specification.

The results of the unit root tests of the four time series are given in Table 5.2[17]. As the tests were undertaken with a small sample (n = 23), interpretation of the results was based on the comparison of the estimated t-statistic with the critical value of -2.8 (Blangiewicz & Charemza, 1990) rather than the standard ADF critical value.

[17] Given the potential loss of information when choosing such a short lag length (Ng & Perron, 1995), we also conducted a unit root tests with up to 4 lags to observe outcome behaviour. In most cases, the results were consistent with the one lag results, although in some instances the series were identified to be I(2) with higher lag lengths.

All four lagged price series were non-stationary using one lag, fulfilling the prerequisite for testing the cointegration of the series.

The optimal lag order for the bivariate models under both cointegration approaches was chosen using the SIC. The SIC suggested a lag order of one for all price pairs except for the pair SA and TAS, for which a lag order of two was found optimal (see Table 5.3). The models under both cointegration analysis approaches were tested under the assumptions of no intercept and no trend, and an unrestriced intercept and no trend.

Table 5.2: Unit root test logged real prices for edible oysters in Australia (n = 23)

Price variable	**Assumption**	**Lag**	**Levels t-statistic**	**Levels p-value**	**First Difference t-statistic**	**First Difference p-value**
NSW	Intercept & Trend	0	-2.35	0.39	-5.25	0.00
	Intercept & Trend	1	-2.60	0.28	-3.87	0.03
QLD	Intercept & Trend	0	-3.50	0.06	-6.15	0.00
	Intercept & Trend	1	-2.77	0.22	-5.93	0.00
SA	Intercept	0	-1.80	0.37	-8.24	0.00
	Intercept	1	-2.48	0.14	-2.80	0.08
TAS	Intercept	0	-1.81	0.37	-5.52	0.00
	Intercept	1	-1.43	0.55	-3.38	0.02

Note: The t-statistic is to be compared with the critical value of -2.8 suggested by Blangiewicz and Charmeza (1990) for time series with a small sample size.

Table 5.3: VAR lag order selection criteria

Price pair	**Lag**	**Schwarz information criterion**
NSW/QLD	0	-3.26
	1	-3.33*
	2	-3.00
NSW/SA	0	-3.29
	1	-4.19*
	2	-4.08
NSW/TAS	0	-3.06
	1	-3.53*
	2	-2.99
QLD/SA	0	-1.75
	1	-2.23*
	2	-1.88
QLD/TAS	0	-1.67
	1	-1.73*
	2	-1.18
SA/TAS	0	-1.62
	1	-2.43
	2	-2.67*

Note: * indicates lag order selected by the criterion.

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Table 5.4: Results for the Johansen test for conintgration

Real prices	Assumption		Rank (ρ) = 0			Rank (ρ) ≤ 1		
		Lag	**Trace t-statistic**	**Trace CV**	**p-value**	**Trace t-statistic**	**Trace CV**	**p-value**
NSW/QLD	No intercept & no trend	1	16.17	12.32	0.01	0.25	4.13	0.68
	Unrestricted intercept & no trend	1	23.08	15.49	0.00	7.13	3.84	0.01
NSW/SA	No intercept & no trend	1	10.10	12.32	0.11	0.10	4.13	0.79
	Unrestricted intercept & no trend	1	23.15	15.49	0.00	2.82	3.84	0.09
NSW/TAS	No intercept & no trend	1	1.60	12.32	0.98	0.55	4.13	0.52
	Unrestricted intercept & no trend	1	12.49	15.49	0.13	0.80	3.84	0.37
QLD/SA	No intercept & no trend	1	9.64	12.32	0.14	0.36	4.13	0.61
	Unrestricted intercept & no trend	1	13.48	15.49	0.10	5.94	3.84	0.01
QLD/TAS	No intercept & no trend	1	3.20	12.32	0.82	0.43	4.13	0.57
	Unrestricted intercept & no trend	1	11.87	15.49	0.16	1.78	3.84	0.18
SA/TAS	No intercept & no trend	2	13.71	12.32	0.03	2.74	4.13	0.12
	Unrestricted intercept & no trend	2	11.25	15.49	0.20	0.11	3.84	0.74

Note: Trace CV is the critical value of the trace test.

Table 5.5: Critical value bounds for ARDL test approach for cointegration

Assumptions (for k=1 cointegration equations, 5 per cent significance level)	**Critical Value Bounds I(0)**	**Critical Value Bounds I(1)**
Unrestricted intercept & no trend [Narayan, 2005]	5.395	6.35
No intercept & no trend [Pesaran *et al.*, 2001]	4.650	5.150

Table 5.6: Results for the ARDL bounds test for conintgration

Assumption	**Lag order***	**Price pairs**	**Wald test F-statistic**	**Results**	**Interpretation of results**
Unrestricted intercept & no trend	1	NSW/QLD	4.310	I(0)	No cointegration
	1	QLD/NSW	8.549	I(1)	Cointegration
No intercept & no trend	1	NSW/QLD	1.251	I(0)	No cointegration
	1	QLD/NSW	8.731	I(1)	Cointegration
Unrestricted intercept & no trend	1	NSW/SA	4.860	I(0)	No cointegration
	1	SA/NSW	6.939	I(1)	Cointegration
No intercept & no trend	1	NSW/SA	0.243	I(0)	No cointegration
	1	SA/NSW	5.182	I(1)	Cointegration
Unrestricted intercept & no trend	1	NSW/TAS	4.113	I(0)	No cointegration
	1	TAS/NSW	2.228	I(0)	No cointegration
No intercept & no trend	1	NSW/TAS	0.235	I(0)	No cointegration
	1	TAS/NSW	0.388	I(0)	No cointegration
Unrestricted intercept & no trend	1	QLD/SA	3.447	I(0)	No cointegration
	1	SA/QLD	2.618	I(0)	No cointegration
No intercept & no trend	1	QLD/SA	0.205	I(0)	No cointegration
	1	SA/QLD	4.663	-	Inconclusive
Unrestricted intercept & no trend	1	QLD/TAS	4.777	I(0)	No cointegration
	1	TAS/QLD	0.849	I(0)	No cointegration
No intercept & no	1	QLD/TAS	0.597	I(0)	No cointegration
	1	TAS/QLD	0.655	I(0)	No cointegration
Unrestricted intercept & no trend	2	SA/TAS	0.873	I(0)	No cointegration
	2	TAS/SA	4.203	I(0)	No cointegration
No intercept & no trend	2	SA/TAS	1.653	I(0)	No cointegration
	2	TAS/SA	4.991	-	Inconclusive

Note: * based on the Schwarz information criterion (see Table 5.3), the F-statistic of the Wald test is to be compared to critical value bounds in Table 5.5.

The Johansen test suggested that there exists a long-run cointegration relationship between NSW/QLD; NSW/SA; and SA/TAS (see Table 5.4). The ARDL bounds testing approach confimed the existence of a long-run relationship between NSW/QLD; and NSW/SA. However, results were found to be inconclusive for the price pairs SA/QLD and SA/TAS (for both under the assumption of no intercept and no trend) since the F-statistic fell within the bounds of the critical values (see Table 5.5 and Table 5.6)

In this case, knowledge about the integration of the underlying variables is required before a conclusive inference can be made (Pesaran *et al.*, 2001). For both cases, we treat the results calculated in the Johansen test as a conclusive inference; that is SA/TAS exhibit a cointegration relationship, while there is no long-run relationship present between QLD/SA (see Table 5.4).

The ARDL bounds testing approach further indicted that a cointegrating relationship only exists between NSW/QLD, NSW/SA and SA/TAS when QLD, SA and TAS, respectively, were dependent variables (see Table 5.6). This may suggest that NSW is the price leader for QLD and SA, and SA leads TAS oyster prices.

Table 5.7: Results for the test of the Law of One Price

Cointegrated price pair	Lag order*	LR Statistic	p-value
NSW/QLD	1	0.002	0.961
NSW/SA	1	14.810	0.000
SA/TAS	2	1.302	0.254

Note: * based on the Schwarz information criterion (see Table 5.3).

Given that the prices of oysters were found to be related, we tested whether the LOP holds in each relationship. As shown in Table 5.7, the null hypothesis of the LOP was rejected at the 5 per cent significance level for the price pair NSW/SA, suggesting that both goods are no perfect subsitutes. The opposite was found for the pairs NSW/QLD and SA/TAS, implying that the goods produced in these States are perfect substitutes. These results are not surprising since QLD and NSW produce SROs and SA and TAS produce Pacific oysters.

5.4.2 Demand analysis

In the second part of the analysis, we estimated the own- and cross-price flexiblities over the short- and long-term. We collapsed the basic formulation of the system of equations into only two equations, one each for the SRO and Pacific oyster markets. Given the trade-off between the lag length and the degrees of freedom in the relatively limited time series, we tested the system by using 2 lags (n = 2) as a representation for a long-run effect.

The models were initially estimated using the seemingly unrelated regression estimation (SUR) method (Zellner, 1962). In this procedure the regression coefficients in all equations are estimated simultaneously for the entire system of equations, which is asymptotically more efficient than single-equation least square estimators (Zellner, 1962). However, substantial multicollinearity was found to exist in the model, mostly as a result of the key variables primarily moving in only one direction. For example, Pacific oyster production increased over the whole period of the data, while prices of both SROs and Pacific oysters declined. As a result, most parameters were found to be not significant, while some parameters had the "wrong" sign. For example, SROs were found to be a complement to Pacific oysters – counter to expectations, common sense and economic theory.

The models were re-estimated jointly using ADMB, a non-parametric non-linear optimisation modelling package for statistical parameter estimation using Markov Chain Monte Carlo methods to derive maximum likelihood estimators (Fournier *et al.*, 2011). Parameter constraints and a penalty parameter in the joint likelihood function were imposed to try and correct for some of the problems caused by multicollinearity in the SUR estimation. As the short-run flexibilities are derived directly, non-positivity constraints could be directly imposed. The long-run flexibilities are derived indirectly (rather than within the initial estimation) so a penalty function needed to be added into the objective function (*i.e.*, minimize the negative of the log likelihood) based on the derived long-run parameter values. This does not prevent the long-run cross-price flexibility from becoming positive, but reduces the likelihood that the two products will be complements.

The model results (Table 5.8) suggest that the prices are inflexible in the short-term for both species, although the short-term own-price flexibility for SROs is not significantly different to -1 (*i.e.,* unitary). In the longer term, SRO prices are relatively flexibile (*i.e.,* < -1). In contrast, both the short- and long-term own-price flexibility for Pacific oysters was relatively inflexible (*i.e.,* > -1). Given that there is an inverse relationship between own price elasticity and flexibility, demand for SROs can be described as relatively inelastic, whereas Pacific oysters face a relatively elastic demand.

Table 5.8: Estimated inverse demand estimations – non parametric estimation

Sydney rock oyster ($\Delta p_{SRO,t}$)			Pacific oyster ($\Delta p_{PO,t}$)		
Coefficient	**Coefficient estimate**	**Std. Error**	**Coefficient**	**Coefficient estimate**	**Std. Error**
α	23.524	7.090***	α	-9.246	5.337**
β_{SRO}	-0.804	0.170***	β_{SRO}	0.000	0.000
β_{PO}	-0.008	0.043	β_{PO}	-0.262	0.050***
γ_{SRO}	-1.134	0.209***	γ_{PO}	-0.682	0.218***
δ_{SRO}	-1.090	0.255***	δ_{SRO}	-0.124	0.078**
δ_{PO}	-0.051	0.055	δ_{PO}	0.399	0.144***
λ_{SRO}	-0.938	0.172***	λ_{PO}	-0.382	0.172**
μ_{SRO}	-1.275	0.328***	μ_{SRO}	-0.135	0.048***
μ_{PO}	-0.138	0.058***	μ_{PO}	0.315	0.204***
φ	2.615	0.613***	φ	-0.046	0.715
τ	1.586	0.669***	τ	-0.006	0.691
ω	-1.382	0.698**	ω	1.236	0.709**
Long-run flexibilities					
$-\mu_{SRO}/\lambda_{SRO}$	-1.359	0.184***	$-\mu_{SRO}/\lambda_{PO}$	0.000	0.000**
$-\mu_{PO}/\lambda_{SRO}$	-0.147	0.045***	$-\mu_{PO}/\lambda_{PO}$	-0.353	0.136***
$-\omega/\lambda_{SRO}$	-1.473	0.703**	$-\omega/\lambda_{PO}$	3.239	2.115*

Notes: *** significant at 1% level, ** significant at 5% level, * significant at 10% level.

Changes in quantities supplied of Pacific oyster had a significant negative impact on price formation in SROs in the long-run but not in the short-term. The negative sign of the estimated cross-price flexibility coefficents denote that the goods are substitutes – higher supplies of Pacific oysters (and its own subsequent lower price) results in a decrease in the price of SROs. In contrast, the cross-product flexibility in the Pacific oyster model is zero, suggesting that SRO supply does not affect the price of Pacific oysters.

Income had a significant negative impact on the price of SROs in the longer term, but a significant positive impact on prices in the short-term. In contrast, the long-run income flexibility was significant and positive. A literal interpretation of this is that SROs are perceived as inferior products, and as incomes rise demand shifts more to Pacific oysters. However, given that real incomes generally increased over the period of the data, this may also reflect the general increase in consumer acceptance of Pacific oyster over time and increased supply to, and consumption in, markets not previously targeted by SROs.

5.5 DISCUSSION

The objective of our study was to investigate whether the markets for the two main commercial edible oysters species in Australia are integrated and thus if the two species are considered the same product. Similarly, we aimed to test whether the markets were delineated by state and/or species. Furthermore, we intended to examine the short- and long-run own- and cross-price flexibilities for the two commercial oyster species in order to identify any price-quantity dynamics.

We found prices of the States that produce the same species to be cointegtrated, that is QLD/NSW for SROs and SA/TAS for Pacific oysters. This is supported by the findings of the test for the Law of One Price which revealed that goods produced in QLD/NSW and SA/TAS are perfect substitutes, respectively. However, we further found that the price of major oyster producing States for each species, NSW and SA, also hold a long-run relationship in which NSW appears to be the price leader. Yet, the products in these two States were found not to be perfect substitues which leades to the conclusion that the markets in NSW and SA are not fully integrated. This result was also refelcted in the asymmetry in the demand models, with SROs being adversely affected by Pacific oyster production but not vice versa.

For the Australian oyster market we can conclude that SROs and Pacific oysters are part of the same market, and prices of the major producing States move together. While this is the case, we need to emphasise that the spatial distribution of sales markets for each oyster species is to be differentiated from the economic definition of a market. While both species were found here to be part of the same economic market, SROs are predominantly sold in QLD and NSW, while Pacific oysters are sold in QLD, NSW, SA, TAS, Victoria and Asia (Trudy McGowan, South Australian Oyster Growers Association, personal communication, 29 April 2013; Tim Paice, Tasmania Department of Primary Industries, personal communication, 30 April 2013).

The estimation of the inverse demand model suggested that price adjustments to changes in quantities supplied within the SROs market are more responsive in the long-run. In the short-run, the price flexibility for SROs is not significantly different from unity, suggesting changes in quantity supplied have an almost equivalent impact on changes in prices received. In the long-term, the own price flexibility is greater than unity (*i.e.*, indicating a relative inelastic demand), so growth in this sector may result in a net decrease in industry revenue. Furthermore, the results suggest that the SRO market treats Pacific oysters as subsitutes, and hence the increase in output of Pacific oysters is likely to have had an adverse impact on SRO prices.

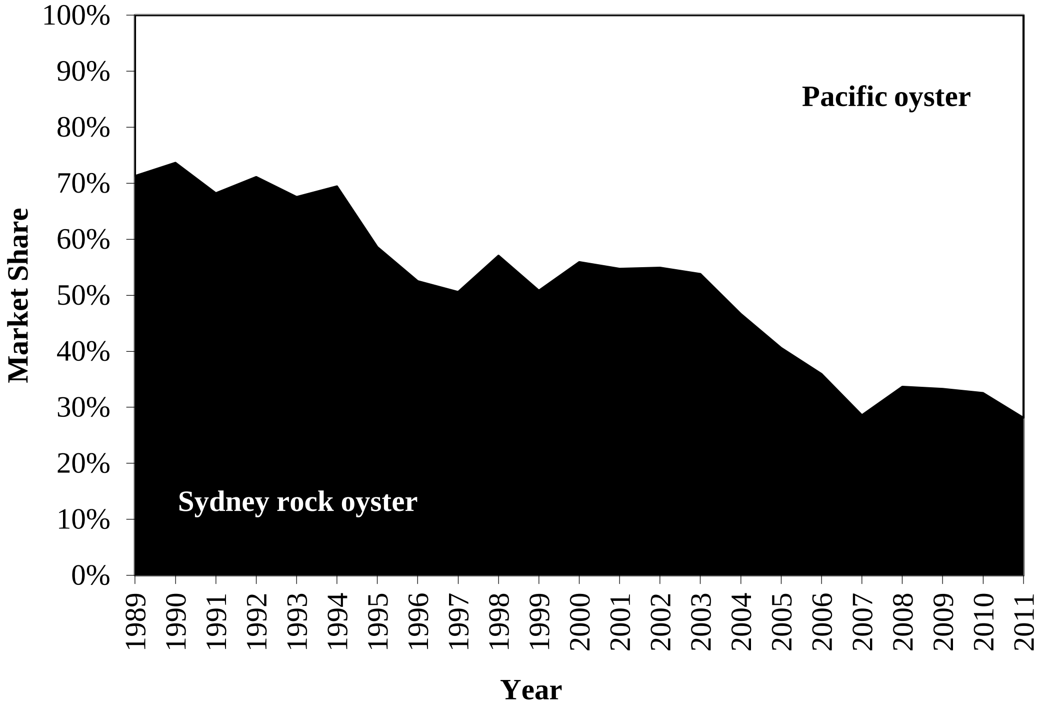
In contrast, both the short- and long-term own-price flexibility for Pacific oysters is relatively inflexible, suggesting that prices have decreased less than proportionally with quantity produced. The long-run flexibility, however, is substantially lower than unity, so that total industry revenue will continue to increase with output.

These results are also supported by recent marketing studies of consumer preferences for oysters. Mueller Loose *et al.* (2013) found evidence of consumer preference for SROs over Pacific oysters in Australia. However, they also found that species type is of low importance compared to other product attributes for consumer choice, particularly the price of oysters (Mueller Loose *et al.*, 2013). This may explain why demand for oysters in our model shifts towards the cheaper and higher volume Pacific oysters over time, subsequently decreasing demand for SROs.

There have been substantial changes in the Australian market for oyster over the period of the data, with Pacific oysters contributing less than 30 per cent of total oyster production at the start of the period and 70 per cent at the end (Figure 5.3). The relatively elastic demand for Pacific oysters may have helped contribute to the development of the industry, as total revenue increased with production. Much of this increased production of Pacific oysters has gone to “new” markets rather than compete directly with the established markets for SROs. The previously established market for SROs is relatively inelastic, while the demand for Pacific oysters is substantially more elastic and income sensitive. There is evidence that the increase in Pacific oysters has had a negative impact on SRO prices. The SRO producers have been able to maintain their prices through reducing their own production, but given the inelastic demand this would have resulted in an overall decrease in revenue to the industry.

A major shortcoming of the study is the limited length of the time series data (23 data points) and the quality of the data which may have affected the quality of the results. The key State and Federal agencies with responsibility for compiling such data provided all that was available. Only annual data have been compiled by these agencies in the past. While monthly price and/or quantity data from institutions along the supply chain of oysters, such as processors and wholesalers, may exist, these data are not publicaly available. Further, given the (geographically) widespread nature of the industry, any individual distributor of oysters may not be representative of the entire industry.

Figure 5.3: Market shares over the period of the data



Source: ABARE (1991, 1993, 1994, 1995, 1996, 1997, 1999, 2000, 2001, 2002, 2003b, 2004, 2005, 2006, 2007, 2008, 2009), ABARE-BRS (2010), ABARES (2011, 2012).

The analysis also assumes that the price of oysters is not affected by other seafood products. Of the other demand studies that explicity included oysters, one suggested that prawns, fish and other shellfish may have a significant impact on oyster prices (Lee & Kennedy, 2008), while the other (Dedah *et al.*, 2011) estimated oyster inverse demand models independent of other seafood as we have done in this study. A priori, the expectation is that quantities supplied of other species would have little impact on oyster prices due to its unique positioning in the diet and the fact that it is almost entirely a domestic market product, and in the case of SROs primarily a local market.

5.6 CONCLUSION

The aim of this study was to establish the market relationship of the key commercial oyster species in Australia.

From the results of the analysis presented in this study it can be concluded that the development of the Pacific oyster industry has appeared to have had an adverse impact on the previously established SRO industry. The demand for the latter species is relatively inelastic, whereas the market for Pacific oysters faces an elastic demand, suggesting the species do not directly compete for the same set of consumers. This is directly supported by the cointegration analysis that suggests that the prices of the two species move separately. However, there is sufficient overlap to result in the growth in production of the introduced species to have had a negative impact on the market for the native species.

The findings from this study should be concidered by the SRO industry management and policy makers, particilarly when concidering the expansion of tripolid Pacific oyster in NSW estuaries, since a further increase in the supply of Pacific oysters could compriomise the future profitability of SRO farming.

The following Chapter 6 will report the findings of an productive efficieny and capacity utilisation analysis of the SRO industry as well as factors that may affect these measures. Findings from the following study will provide information about production factors that may have affected the economic viability of the industry over time.

Chapter 6: Productive efficiency and capacity utilisation of the Moreton Bay SRO industry

6.1 INTRODUCTION

Measuring the performance of firms is a relative concept that can provide policy makers as well as firm and industry managers information about the level of productivity present in an industry. The understanding of the relationship between exogenous production factors (*e.g.*, degree of government regulation, age of labour force, weather, and pollution) and the productive performance of firms is of particular interest for managers and regulators since these factors can be key determinants for business success or failure.

This study focussed on assessing the performance of firms in Queensland's Moreton Bay, the industry's northern most cultivation area, appeared to be particularly challenged over the past decades. At one point, Moreton Bay was the largest oyster producing region in Australia, supplying the Sydney and Melbourne markets as well as Brisbane (G. Smith, 1981). Overfishing, disease and changes in market conditions have all contributed to the decline in the Moreton Bay industry (G. Smith, 1981). However, the area available for production (*i.e.*, under commercial leases) and number of farmers is still one of largest of all estuaries along the Australian east coast, yet total production is relatively low in comparison to other areas (ABARES, 2013; NSW DPI, 2013a). In Moreton Bay roughly 17 per cent of all SRO lease holders are located, yet they produce less than 2 per cent (by value) of Australian SRO production (ABARES, 2013).

The Oyster Industry Management Plan for Moreton Bay Marine Park (QLD DPI&F, 2008a) includes the objectives of increasing production from the existing leases, to promote the commercial industry development and to improve the image of the industry. The related policy on management of non-productive oyster leases (QLD DPI&F, 2007) includes a provision for minimum production levels in oyster leases and the requirement to "show cause" for non-productive farmers as to why they should retain their lease.

Increasing production from a given set of leases can only occur through increased efficiency and/or capacity utilisation. To determine the extent of any potential production increases, the existence and causes of any inefficiency and/or capacity underutilisation needs to be determined. It is unclear whether the current situation of the SRO industry in Moreton Bay is due to oyster farmers' business choices, farmers' personal characteristics or whether environmental conditions in the Moreton Bay limit the capacity of the oyster industry in this region.

The aim of this study was to assess the productivity of the industry through measures such as technical efficiency, scale efficiency, allocative efficiency and capacity utilisation, and to assess the factors driving these measures. The aim of this study corresponds with aim 3 of the research program. The different productivity measurement approaches are being increasingly applied in aquaculture as a means of providing information to policy makers on how to improve productivity in these industries (Iliyasu *et al.*, 2014). We used a two-stage analysis approach, with productivity measures derived in the first stage using multi-output data envelopment analysis (DEA). In the second stage, we estimated the influence of oyster farmers' personal characteristics and environmental conditions at different production sites on the derived efficiency and capacity scores.

6.2 MORETON BAY SYDNEY ROCK OYSTER INDUSTRY

The history of the SRO industry in Moreton Bay, at the mouth of the Brisbane River, dates back to European settlement in Australia in the early 1800s (G. Smith, 1985). The production of oysters in Moreton Bay peaked in the early 1900s (Lergessner, 2006; G. Smith, 1985). The decline in oyster production in Moreton Bay at that time was linked to mudworm infestation and severe depletion of natural oyster banks (Lergessner, 2006; G. Smith, 1981, 1985). Since then oystering in Moreton Bay continued to be undertaken on a smaller scale in comparison to a relatively large industry in NSW. Currently there are 69 oyster farming businesses that take up a total of 97 approved leases in this estuary (John Dexter, Queensland Department of Agriculture, Fisheries and Forestry, personal communication, 24 March 2014). In 2011-12 the total annual production volume of oysters in Moreton Bay was about 132,294 dozen or about 85 metric tons valued at approximately 513,400 Australian Dollars (Wingfield & Heidenreich, 2013). The major market for

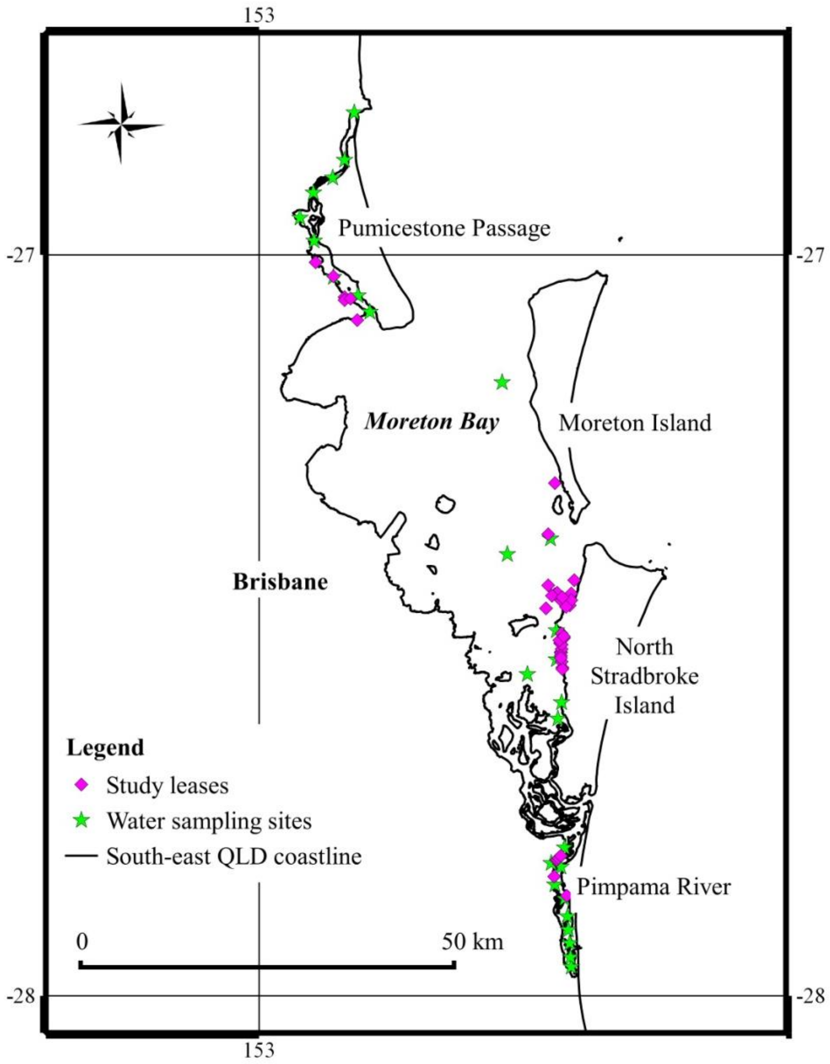
SROs from the Moreton Bay is Brisbane, a metropolis with a population of 1.8 million people.

Moreton Bay is one of currently 65 Ramsar sites in Australia[18] (Australian Government, 2014), and the Bay is designated as a multiple use marine park. The Oyster Industry Management Plan provides an administrative framework for managing the oyster industry within the marine park. The plan is accredited under *Marine Parks Regulations 2006* and oyster growers who conduct their operations within the framework of the plan do not require a marine parks permit.

There are currently four areas allocated for oyster growing in Moreton Bay, these are: Moreton Island (hereafter referred to as Eastern Banks), North Stradbroke Island (includes Myora and Canaipa, hereafter referred to as Eastern Bay), Pimpama River and Pumicestone Passage (Figure 6.1).

[18] Ramsar wetlands are representative, rare or unique wetlands, or are important for conserving biological diversity (Australian Government, 2014). These are included on the list of wetlands of international importance developed under the Ramsar convention (Australian Government, 2014).

Figure 6.1: Moreton Bay oyster growing areas



Note: Moreton Island production area is referred to as Eastern Banks and North Stradbroke Island production area is referred to as Eastern Bay.

The oyster areas are located within general use, habitat and conservation zones of the Moreton Bay Marine Park (QLD DPI&F, 2008b). Both (approved) commercial and recreational fishing activity can occur within oyster areas as long as the activity does not interfere with the aquaculture operation. The total area allocated to oyster leases covers about 435 hectares, which is less than one per cent of the total area of the marine park (QLD DPI&F, 2008b).

The Moreton Bay oyster industry is managed by the Queensland Department of Agriculture, Fisheries and Forestry (QLD DAFF). Resource allocation authorities issued under the *Fisheries Act 1994* provide the holders the exclusive right to cultivate and to take oysters from the designated lease areas. Resource allocation authorities are issued for a period of up to 30 years.

SROs are filter feeding organisms and naturally occur in estuaries where the intertidal change provides a suitable habitat. This native Australian oyster species takes about 2.5 to 3.5 years to grow the smallest and largest marketable size, respectively. SROs are typically harvested in the warmer summer months ranging from October to March.

Being filter feeders, they can accumulate any type of pollution present in the water. The monitoring of the safety of oyster for human consumption includes regular water sampling at oyster areas and oyster meat sampling, with supply of oysters from particular leases stopped should water and meat samples not comply with food safety standards. Run-off from agricultural production in nearby river catchments can carry sediments into the estuary which may negatively affect water quality, oyster growth and also food safety. This is particularly problematic after high rainfall events, which also has the effect of reducing salinity further affecting the health of the oysters. The presence of high *E. coli* levels in meat samples, caused, for example, by sewage spills, is also observed occasionally, and leads to ceasing the supply of oysters from affected areas.

6.3 METHODS

In this study, a two-stage analysis procedure was used to analyse and assess inefficiency and capacity utilisation for two reasons. First, different producers harvest their oysters at different grow-out periods, resulting in a mix of size grades which requires a multi-output method of assessment. Second, anecdotal evidence suggested that there were a range of different approaches to production, ranging from effectively hobby farm to commercial enterprise. Statistical approaches, such as stochastic distance function approaches (Coelli & Perelman, 2000; Färe & Grosskopf, 2000; Grosskopf *et al.*, 1995; O'Donnell & Coelli, 2005; Pascoe *et al.*, 2010) effectively assume a common underlying production technology. The limited number of observations also makes parametric estimation of distance function models difficult. Consequently, data envelopment analysis (DEA) was undertaken in order to assess the level of efficiency and capacity utilisation for the Moreton Bay SRO industry. DEA is commonly applied in studies in the context of food production, fisheries and aquaculture (*e.g.*, Alam, 2011; Chambers *et al.*, 2011; Mugera, 2013; Reid *et al.*, 2003; Tingley & Pascoe, 2005; Tingley *et al.*, 2005; Vestergaard *et al.*, 2003) and is more commonly applied in general than parametric approaches for productivity analysis (Lampe & Hilgers, 2014).

6.3.1 DEA (first stage)

DEA is a non-parametric, linear programming method for measuring the relative efficiencies of individual decision making units (DMUs) within a group of individual DMUs, given a set of inputs and produced outputs (Hoff, 2007). A DMU is a term that is frequently used in economics to refer to an individual or entity (*e.g.*, firms, industries, countries) that are responsible for making production decisions (*e.g.*, Azizi & Ajirlu, 2010; Charnes *et al.*, 1978; Humphreys *et al.*, 2014). In this study, the term DMU refers to individual oyster farmers who operate within the industry under given industry management plans and regulatory settings. Individual oyster farmers make decisions about how they will undertake oyster production, and that these decisions are reflected in the chosen production inputs and the obtained production outputs. For example, oyster farmers make decisions about the quantity and allocation of production inputs (*e.g.*, labour input). Farmers also make decisions about the use of the total lease area (fixed inputs) they hold, and about their output production mix (*e.g.*, harvest of small, medium or large sized oysters). The outcome of these decisions is the quantity harvested.

Given this notion, DEA can be used as a benchmarking tool to assess the performance of individual DMUs against the efficient frontier of the group which is defined by the most efficient DMUs within the group (Coelli *et al.*, 2005). However, the frontier approach does not assume that most efficient DMUs within a group are fully efficient (Coelli *et al.*, 2005); it rather provides a benchmark derived from observed efficient (or best-practice) DMUs.

A key feature of DEA is that it is readily able to incorporate multiple outputs into the analysis. This is particularly relevant since oysters are typically produced in three market sizes, that are small (bottle), medium (bistro) and large (plate). DEA does not impose any assumption about the functional form of the production function and thus is less prone to mis-specifications. However, as a non-parametric method, DEA cannot account for statistical noise and hence efficiency estimates may be biased if the production process is characterised by stochastic elements (Coelli *et al.*, 2005). This is less problematic for capacity utilisation estimation, as the process for deriving unbiased estimates of capacity utilisation (shown below) has a benefit in that much of the effects of random error are cancelled out (Holland & Lee, 2002).

In this study, an output-orientated DEA model was used as the aim was to determine the maximum output of the *i*th DMU given observed inputs. The basic assumption of the output-oriented DEA is that output vector of the *i*th DMU is expanded radially until the combination of inputs of the respective DMU reached the efficient output frontier of the production possibility set for the group of DMUs. For a group of *N* DMUs that each have *K* outputs and *S* inputs, the maximum output of the *i*th DMU is determined by the following linear programming problem:

$$\begin{aligned} &\max_{z_i,\Phi_i} \Phi_i \\ \text{s.t.} \quad &\Phi_i y_{k,i} \le \sum_{i=1}^{N} z_i y_{k,i} \qquad \text{k} \in [1,\ldots,K] \\ &x_{s,i} \ge \sum_{i=1}^{N} z_i x_{s,i} \qquad \text{s} \in [1,\ldots,S],\ \text{i} \in [1,\ldots,N] \end{aligned} \tag{6.1}$$

Where Φ is a scalar indicating by how much the output of each DMU can be increased relative to the efficient frontier of a group of DMUs; $y_{k,i}$ is the amount of output *k* by DMU *i*; $x_{s,i}$ is the amount of input *s* used by DMU *i*; and z_i are weighting factors. The input set can be separated into variable inputs (*e.g.*, labour), where values of the variable may change in short-run and fixed inputs (*e.g.*, the area of the lease), where values can only change in long-run. In order to account for the changes in the relationship between fixed inputs and outputs we can impose variable returns of scale (VRS), $\sum_i^N z_i = 1$, which allows for increasing, constant and decreasing returns within the production process. Various authors (Banker *et al.*, 1984; Färe *et al.*, 1983) suggested the use of VRS in DEA models to account for situations such as imperfect competition and government regulation that may cause a firm to be unable to operate at optimal scale (Coelli *et al.*, 2005). Without such a restriction, constant returns to scale (CRS) are assumed.

Technical efficiency (TE) is a measure that reflects the ability of DMUs to obtain maximum output from a given input set. The general form of TE is given by:

$$TE = \Phi_i^{-1} = \Phi_1^{-1} \tag{6.2}$$

The value obtained for TE is the efficiency score for the *i*th DMU. The derived efficiency scores lie in the interval [0,1], with a value of 1 indicating a point on the frontier and hence a technically efficient firm.

Capacity represents the potential output given a set of fixed input, assuming that these are all fully utilised. Most applied studies are concerned with the level of capacity utilisation, which measures the extent to which fixed inputs are being fully utilised (Dupont *et al.*, 2002; Tingley & Pascoe, 2005; Vestergaard *et al.*, 2003). Capacity utilisation (CU) is derived by solving the above model (equation 6.1) using fixed inputs only. The resultant technical efficiency measure, Φ_2, can be used to derive a capacity utilisation score by:

$$CU(observed) = \frac{y}{\Phi_2 y} = \frac{1}{\Phi_2} = \Phi_2^{-1} \qquad (6.3.1)$$

Färe *et al.* (1989) argued that this CU measure may be biased downward, since it captures both capacity utilisation and technical efficiency. Consequently, an adjustment is required to separate out the CU component to correct for the bias. Färe *et al.* (1989) suggest that an unbiased measure of CU may be calculated as:

$$CU(unbiased) = \frac{\Phi_1 y}{\Phi_2 y} = \frac{\Phi_1}{\Phi_2} \qquad (6.3.2)$$

As noted above, this measure is also less susceptible to random error (Holland & Lee, 2002).

The scale efficiency measure provides information about the production scale or level of a DMU compared to other DMUs in a group. The CRS assumption is appropriate when DMUs are operating at an optimal scale (Coelli *et al.*, 2005). However, the use of VRS imposes the possibility that the scale of production could affect the efficiency of DMUs. The scale efficiency measure is estimated as the ratio of technical efficiency with constant returns to scale (TE(CRS)) to technical efficiency with variable returns to scale (TE(VRS)), a TE(CRS) and a TE(VRS). The relationship can be described as:

$$SE = TE(CRS) / TE(VRS) \qquad (6.4)$$

If the results for TE(CRS) and TE(VRS) scores for a DMU differ, it indicates that this DMU is operating at a scale that is less than efficient. Hence, the results provide an indication as to how close a DMU is to its (technically) optimal scale.

The allocative efficiency (AE) measures is used to identify the degree to which DMUs are adopting strategies that lead to optimisation of revenue from the production process, given the relative prices of each output. The estimation of the revenue efficiency with VRS and TE(VRS) are required for the estimation of allocative efficiency scores.

Revenue efficiency can be obtained by solving the following revenue maximization DEA problem:

$$\begin{aligned} &\max_{z_i, y} \sum_{i=1}^{N} p_{k,i} \varphi_k y_{k,i} \\ s.t. \quad &\sum_{i=1}^{N} z_i y_{\ k,i} \leq y_k \qquad \mathrm{k} \in [1,...,K] \\ &\sum_{i=1}^{N} z_i x_{s,i} \leq x_s \qquad \mathrm{s} \in [1,...,S], \ \ \mathrm{i} \in [1,...,N] \\ &\sum_{i=1}^{N} z_i = 1, \ \ \mathrm{z}_i \geq 0 \end{aligned} \tag{6.5}$$

Where $\sum_i^N p_{k,i}\, \varphi_k y_{k,i}$ is the observed revenue, with $p_{k,i}$ as output prices that vary between DMUs and φ_k represents the linear expansion factor to the revenue frontier. The revenue efficiency is given by:

$$RE(VRS) = {\varphi_k}^{-1} \tag{6.6}$$

The output-mix allocative efficiency measure is then obtained as:

$$AE = RE(VRS) \,/\, TE(VRS) \tag{6.7}$$

Allocative efficiency scores provide information about the degree to which changes in the production mix (*i.e.*, production of small, medium, large and other sized oysters) could enhance the DMU’s revenues.

6.3.2 Second stage

The ability of DMU’s to convert input into outputs can be influenced by exogenous variables that characterise the environment in which production takes place (Coelli *et al.*, 2005). These exogenous factors can be observable (*e.g.*, government regulation, age of labour) and unforeseen (*e.g.*, disease, weather) (Coelli *et al.*, 2005). Previous studies that assessed the effect of drivers of efficiency derived in a DEA most commonly use Tobit analysis (*e.g.,* Ahmed *et al.*, 2011; Tingley & Pascoe, 2005; Vestergaard *et al.*, 2003). Efficiency scores, defined as ratios of actual output to the frontier value of the output, must lie between 0 and 1 or equal 0 or 1. Thus, the application of Tobit analysis is frequently used in the second stage analysis for [0,1] limited and censored distribution of the dependent variable (Hoff, 2007; Kieschnick & McCullough, 2003; McDonald, 2009). Hoff (2007) compares Tobit and Ordinary Least Squares (OLS) estimation methods and shows that while the Tobit approach may be adequate, the OLS approach may in many cases replace Tobit as a sufficient second stage DEA model. McDonald (2009) argues that DEA efficiency measures are not censored but rather fractional or normalized with a heteroskedastic distribution. In this case, Tobit analysis may produce mis-specified estimates, and OLS may be a more appropriate approach (McDonald, 2009).

In this study, we applied both Tobit and OLS approaches to estimate how demographic characteristics and environmental conditions may affect productivity measures derived for oyster farmers in Moreton Bay.

6.4 DATA

Annual cross-sectional oyster production data were made available by the QLD DAFF. The production data set included annual records covering the period between 1997/98 and 2011/12 (15 years) for a total of 39 oyster farmers who gave the consent to QLD DAFF for their data to be used for the research purpose of this study. Since individual oyster farmers (the DMUs within the oyster industry) take decisions about their individual production process it can be assumed that these choices are reflected in the available production input and output data for each observation.

The production data included information about production output volume (number of dozens of oysters) and production values for four different product grades (sizes), namely bottle (small), bistro (medium), plate (large) and other. Product prices were derived from the production volume and values. In cases in which production values were unavailable for an individual, we used average annual prices derived from the available observation for each year.

The production data also included information on labour inputs, separated into three categories: lease owner full-time equivalent (FTE)[19], permanent FTE and casual FTE. Information about the total leased area size (hectare) per lease owner as well as the geographic location of the leases was used as fixed inputs. For larger scale oyster cultivation, there are commonly a number of leases used for different stage in the cultivation process. For example, the initial phase of catching of oysters spat usually requires areas where oyster spat is available in abundance while grow-out leases are used to fatten the oysters and depuration leases are used for purification prior to the harvest of oysters. Information collected from farmers that held more than one lease did not cover the particular use of each oyster leases during the cultivation process. Thus, the available production data only reported total production volumes and values per lease owner.

The total number of observations initially used for the first stage DEA was 300 (*i.e.*, all observations). However, due to limitations in environmental and demographic data used in the second stage (see below), we also performed the first stage DEA on a sub-sample of 113 observations for which complete data were available. Descriptive statistics of the full and sub-sample of the data are shown in Table 6.1.

For the second stage analysis, demographic characteristics of oyster farmers and data of environmental parameters in proximity of the respective oyster leases were used. An oyster farm survey was undertaken by the authors of this study in 2012, which provided information about the socio-economic characteristics of Moreton Bay oyster farmers (Table 6.2, see also Chapter 4). The collection of this primary data set was approved by the Queensland University of Technology's Human Research Ethics Committee (approval number: 1200000303). The participants of the survey were made aware in written form about the confidential use of the data for research purposes and that the consent to use the data for this purpose was provided by the participants in completing the survey and returning it to the authors of this study. In order to comply with ethics standards, none of the participants or their business was identifiable in this study.

[19] Based on 40 hour work per week

Table 6.1: Descriptive statistics of production data

Variable	**Mean** Full-sample [sub-sample]	**Coeff. of variation** Full-sample [sub-sample]
Outputs quantity (dozen)		
Bottle grade	1,418 [1,925]	272% [201%]
Bistro grade	1,198 [1,314]	225% [222%]
Plate grade	612 [523]	221% [166%]
Other grade	513 [720]	288% [269%]
Output price per dozen		
Bottle grade	3.48 [3.87]	38 % [32%]
Bistro grade	4.92 [5.69]	40% [39%]
Plate grade	6.57 [7.42]	37% [30%]
Other grade	3.94 [4.47]	58% [61%]
Inputs		
Hectare size	3.29 [10.23]	66% [188%]
Total labour (FTE)	0.13 [0.17]	218% [213%]

The socio-economic characteristics of Moreton Bay oyster farmers were matched with the production data where available. The second stage analysis was undertaken on a sub-sample of the production data as demographic information was not available for all farmers. For observations that included demographic information, we augmented records of continuous variables (*e.g.*, age, years of experience) to account for the continuous involvement of farmers in the industry. Categorical data (*e.g.*, level of farmer education) was assumed to be constant over time, with dummy variables also included to capture any effects of gender (Male = 1), education (tertiary educational = 1) and generation (1 = more than one generations of experience in oyster farming within the family) on productivity.

Table 6.2: Socio-economic characteristics of the Moreton Bay oyster industry

Socio-economic characteristics	Results
Gender(per cent of all farmers)	
Female	17%
Male	83%
Age (years)	
Minimum	29
First quartile	51
Average	57.5
Median	56.5
Third quartile	65
Maximum	76
Farmers younger than 35 years	4%
National origin[#]	
Australian born	96%
Experience in oystering (years)	
Minimum	0
First quartile	4
Average	14
Median	10
Third quartile	28
Maximum	50
Educational attainment[#]	
Year 10 certificate & below	30%
Year 12 certificate	39%
TAFE degree / Apprenticeship	4%
University degree	26%

Socio-economic characteristics	Results
Household	
Number of people living in household	2.1
Number of children	2.2
***Annual income* (weekly disposable income)**[1,#]	
$0-$40,000 ($0-$669)	48%
$40,001-$60,000 ($670-$922)	5%
$60,001-$80,000 ($923-$1,174)	10%
$80,001-$100,000 ($1,175-$1,411)	29%
$100,001-$120,000 ($1,412-$1,646)	0%
Over $120,000 (over $1,646)	10%
Off-farm income[#]	73%
Proportion of total income from oyster farming (average)[#]	14%
Other	
First Generation is oyster farming[#]	83%
Average number of generation in oystering if not first generation	2.5
Member in farming association[#]	100%
Experience with other fish / shellfish species[#]	13%

Notes: Data collected in a farm survey in 2012 (refer to Chapter 4 for details). Weekly disposable income (net income) estimates for income brackets derived from Australian Taxation Office (2013). [#] Per cent means, data represent as proportion on all farmers. All income values are in Australian Dollars.

Environmental data for Moreton Bay were obtained from Healthy Waterways Ltd. (2012). This data set contained monthly records for water quality indicators collected at estuarine zones within Moreton Bay. The environmental data included records ranging from 2000 to 2012. Although earlier records were available, they were collected by different agencies and contain less frequent and spatially distributed information and were therefore excluded from this analysis. We mapped oyster production areas against water collection sites and only used data for sites that were in close proximity to the production areas. Details are provided in Figure 6.1.

The key variables considered were salinity, water temperature, dissolved oxygen, light penetration, turbidity, dissolved nitrogen and phosphorus, chlorophyll-a levels, and acidity (pH) (see Table 6.3). The relationship between oyster shell and flesh growth and environmental factors is very complex, depending on average as well as extreme levels and their duration.

Table 6.3: Environmental variables used in the analysis

Environmental variable (unit)	**Mean**	**Coeff. of variation**
Salinity (ppt)	31.98	16%
Temperature (°C)	22.47	4%
Dissolved oxygen (%)	94.52	12%
Light penetration	3.34	57%
Turbidity (NTU)	5.92	116%
Dissolved total nitrogen (mg/L)	0.25	76%
Dissolved total phosphorus (mg/L)	0.02	52%
Chlorophyll-a (µg/L)	2.46	147%
pH	7.96	6%

Note: Values refer to the zones Eastern Banks (sites 506, 507), Eastern Bay (sites 310-314, 502), Pimpama River (site 1801) and Broadwater (105-123) in the data set obtained from Healthy Waterways Ltd. (2012) as they best represent areas in which oyster leases are located.

Several of these variables are believed to have a direct impact on the growth and survival of the oysters. A low level of salinity may compromise the development and growth as oysters close their valves and stop feeding at low salinity levels (Rubio Zuazo, 2008). Prolonged rainfall periods typically lead to low salinity levels in estuaries. Optimal salinity levels range from 25 to 35 parts per thousand (ppt) (Dove & O'Connor, 2007; Holliday, 1995). However, the salinity tolerance varies significantly depending on the life stage of oysters, with younger oyster tolerating 15-39 ppt and adult oysters tolerating 0-50 ppt for limited period of time (Holliday, 1995). The optimal water temperature for SRO development and growth ranges from 14-28 °C with a tolerance of 11-30 °C (Dove & O'Connor, 2007; Holliday, 1995). Low levels of dissolved oxygen also affects the metabolism of oysters (Bayne *et al.*, 1999). Highly acidic in water affects shell formation of oysters and, thus, their growth (Parker *et al.*, 2011), with the optimal pH range for SRO being 6.5-8.5 (Dove, 2003). High level of turbidity, in particular of inorganic particles, may lead to congested gills affecting their ability to filter water and extract food (Grant *et al.*, 1997). Turbidity typically increases after rain events.

Other environmental variables affect the supply of the food source for oysters, indirectly affecting their growth. The depth to which light penetrates the water affects the presence of phytoplankton/microalgae biomass, an energy source for oysters. High level of turbidity also reduce the amount of light and there for the food supply (Grant *et al.*, 1997). Similarly, a low level of oxygen may affect phytoplankton/microalgae biomass production. Chlorophyll-a is a direct measure of the presence of phytoplankton.

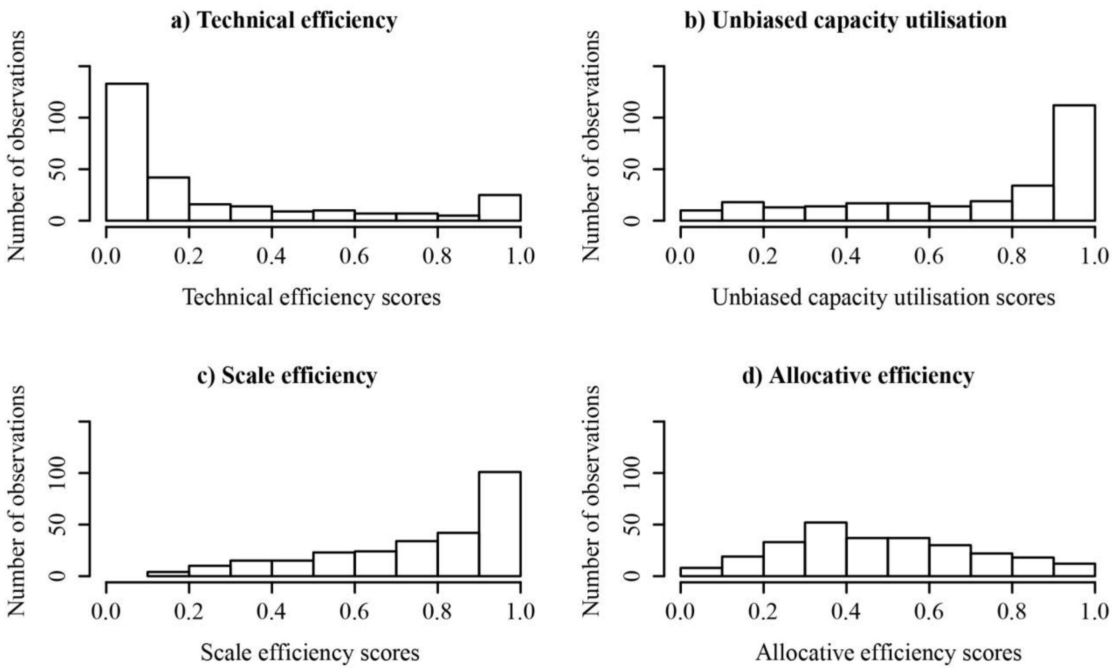
The level of dissolved nutrients can reduce the food safety of the oyster, with too high levels leading to harvesting being delayed. Nutrient levels also may affect the production of the food supply, with excessive levels leading to algal blooms, and in extreme cases eutrophication. Dissolved total nitrogen measures the presences of all forms of nitrogen (*e.g.,* nitrate, nitrite, ammonia) in water. Urban and agricultural runoff, industrial wastes, and sewage effluents typically lead to high nitrogen concentrations in estuaries. Oysters are able to assimilate nitrogen from the water in their soft tissue and shells (Kellogg *et al.*, 2013). Dissolved total phosphorus is a measure for the presence of all forms of phosphorus present in water. The presence of high levels of phosphorous in estuaries can be attributed to similar sources as for nitrogen (see above). Oysters are able to assimilate phosphorus from the water in their soft tissue and shells (Higgins *et al.*, 2011).

Monthly records were used to obtain an annual average value for each environmental variable at each production area. Extreme values, such as annual minima or maxima, were not considered appropriate for our analysis as the data set does not provide information about the frequency and duration of extreme values within a month. Such information would have been vital for estimating the magnitude and significance of extreme environmental values on productivity (*e.g.*, Dove, 2003; Holliday, 1995). Since demographic observations were unavailable for leases in the Pumicestone Passage we could only include three for the four oyster production areas in Moreton Bay in the second stage analysis. Dummy variables for Eastern Bay and the Eastern Banks oyster growing areas (Figure 6.1) were included to account for any spatial effects that are not picked up by environmental variables.

6.5 RESULTS

The DEA analysis revealed that a high proportion of oyster businesses in Moreton Bay were relatively inefficient (Figure 6.2.a, Table 6.4). In contrast, most of the oyster businesses operated at a high or full unbiased capacity utilisation (UCU) rate (median of 0.85, Table 6.4). That is, the businesses are mostly providing an appropriate amount of variable inputs (labour), but are not using it efficiently. The majority of oyster businesses operate close to or at the technical optimal scale (Figure 6.2.c, Table 6.4) with a median scale efficiency scores of 0.81. Given this, we can conclude that most businesses in this industry would not be able to significantly increase their productivity by changing their level of activity (labour) or the scale of their operations.

Figure 6.2: Distribution for capacity utilisation and efficiency scores (all observations)



Allocative efficiency scores were found to be relatively dispersed (Figure 6.2.d, Table 6.4). Allocative efficiency compares technical efficiency against revenue efficiency and thus, indicates the degree of which changes in the output mix (different grades of oysters sold) could enhance the revenue of businesses in the industry. The wide distribution of allocative efficiency scores indicates that the current product mix is not optimal for a high proportion of the industry.

Table 6.4: Summary of the key DEA results (all observations)

Capacity utilisation / efficiency measure	Min.	Median	Mean	Max.	Standard deviation
Observed CU	0.000	0.059	0.177	1.000	0.267
Unbiased CU	0.018	0.850	0.716	1.000	0.305
TE (VRS)	0.000	0.099	0.249	1.000	0.311
Scale efficiency	0.104	0.808	0.751	1.000	0.232
Allocative efficiency	0.000	0.438	0.477	1.000	0.230

Notes: CU for capacity utilisation, TE (VRS) for technical efficiency (variable returns of scale).

The derived technical efficiency scores, capacity utilisation scores and scale efficiency scores for the sub-sample used in the first stage analysis follow a very similar distributional pattern with only minor variation in comparison to the results obtained in the analysis using the full data set (Figure 6.3, Table 6.5). The distributions of allocative efficiency scores using the full data set and the sub-sample set show differing patterns (see Figure 6.2.d, Figure 6.3.d, Table 6.4, Table 6.5), which suggests that the results using the sub-sample data set should be interpreted with caution.

Figure 6.3: Distribution for capacity utilisation and efficiency scores (sub-sample)

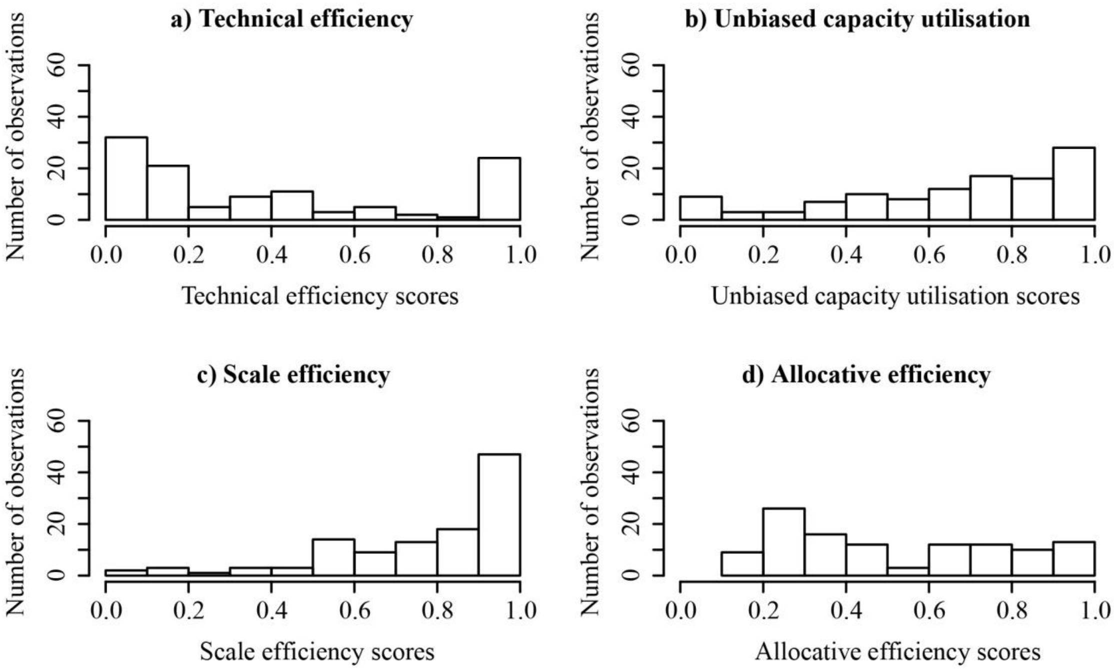


Table 6.5: Summary of the key DEA results (sub-sample)

Capacity utilisation / efficiency measure	Min.	Median	Mean	Max.	Standard deviation
Observed CU	0.000	0.114	0.262	1.000	0.313
Unbiased CU	0.010	0.752	0.664	1.000	0.293
TE (VRS)	0.001	0.291	0.398	1.000	0.367
Scale efficiency	0.038	0.847	0.778	1.000	1.000
Allocative efficiency	0.113	0.445	0.518	1.000	0.271

Notes: CU for capacity utilisation, TE (VRS) for technical efficiency (variable returns of scale).

The results for the second stage OLS and Tobit estimations are shown in Table 6.6 and Table 6.7. Both OLS and Tobit estimation methods generate consistent results with only minor differences in significance levels in TE and UCU model results. The TE and UCU models were jointly significant, although the explanatory power of the OLS models were generally low. While the allocative efficiency model was jointly significant using the Tobit approach, variables in the OLS model were not jointly significant. Thus, the second stage analysis results for the allocative model should be interpreted with caution.

The OLS estimation of the relationship between the assessed exogenous production factors and the derived TE scores suggest that the age of farmers has negative significant impact on TE scores (Table 6.7). Tertiary educational, and two or more generations within families in oyster farming also had a negative effect on TE scores compared to farmers who have a lower educational level and are first generation in oyster farming. TE is likely to be positively influenced by a higher level of experience as an oyster farmer. Gender did not affect TE in our estimation.

Light penetration, turbidity, nitrogen, phosphorous, chlorophyll and pH were all found to be significant, as expected. The spatial dummy variables were not significant, suggesting any differences between areas were adequately captured by the environmental variables.

An OLS regression analysis using scaled independent variables provides us with information about the magnitude and rank of the impact that significant exogenous variables have on the TE score (Table 6.7). Based on this, we can see that most demographic and environmental conditions affect the level technical efficiency of oyster businesses, with the latter having a generally greater influence.

Table 6.6: Tobit analysis results

TOBIT	TE					UCU					Allocative				
Coefficients	**Estim.**	**Std. Err.**	**p-val.**	**Magn.**	**Rank**	**Estim.**	**Std. Err.**	**p-val.**	**Magn.**	**Rank**	**Estim.**	**Std. Err.**	**p-val.**	**Magn.**	**Rank**
(Intercept)	0.311	0.283	0.273			0.469	0.220	0.033			6.967	7.537	0.355		
Male	0.018	0.172	0.919	0.018		0.462	0.135	0.001	0.462	2	0.186	0.137	0.175	0.186	
Age	-0.291	0.059	0.000	0.291	5	-0.003	0.049	0.950	0.003		0.001	0.004	0.884	0.007	
Experience	0.141	0.044	0.001	0.141	8	0.016	0.035	0.654	0.016		-0.002	0.003	0.626	0.017	
Education 2	-0.219	0.114	0.055	0.219	6	-0.116	0.091	0.202	0.116		0.105	0.090	0.243	0.105	
Generation 2	-0.162	0.101	0.110	0.162		0.166	0.081	0.039	0.166	3	0.135	0.078	0.085	0.135	3
Salinity	0.019	0.058	0.749	0.019		-0.031	0.046	0.504	0.031		0.083	0.043	0.052	0.088	4
Temperature	0.057	0.041	0.172	0.057		0.009	0.033	0.793	0.009		-0.044	0.077	0.567	0.019	
Dissolved Oxygen	-0.008	0.063	0.897	0.008		-0.073	0.050	0.144	0.073		-0.017	0.021	0.421	0.039	
Light penetration	-0.307	0.107	0.004	0.307	4	0.068	0.082	0.412	0.068		-0.063	0.048	0.184	0.109	
Turbidity	0.592	0.172	0.001	0.592	1	-0.036	0.135	0.792	0.036		0.045	0.060	0.454	0.096	
Nitrogen	0.171	0.090	0.056	0.171	7	-0.010	0.072	0.889	0.010		-0.409	1.818	0.822	0.016	
Phosphorous	-0.351	0.134	0.009	0.351	3	-0.064	0.107	0.549	0.064		29.642	27.338	0.278	0.112	
Chlorophyll-a	-0.373	0.124	0.003	0.373	2	0.011	0.097	0.911	0.011		-0.150	0.186	0.419	0.075	
pH	0.128	0.068	0.062	0.128	9	-0.027	0.055	0.621	0.027		-0.881	0.880	0.317	0.053	
Eastern Banks	-0.290	0.454	0.522	0.290		0.657	0.359	0.067	0.657	1	0.773	0.348	0.026	0.773	1
Eastern Bay	0.301	0.307	0.328	0.301		-0.342	0.237	0.149	0.342		0.494	0.234	0.035	0.494	2
Log Sigma	-1.136	0.079	0.000			-1.368	0.075	0.000			-1.363	0.069	0.000		

Model Statistics	**TE**	**UCU**	**Allocative**
Left-censored:	0	0	0
Uncensored:	90	95	107
Right-censored:	23	18	6
Log-likelihood:	-46.663	-18.723	-13.128
LR chi-squared:	71.116	62.660	23.081
p-value:	0.000	0.000	0.000

Note: Magn. for magnitude

Table 6.7: OLS analysis results

OLS	TE					UCU					Allocative				
Coefficients	**Estim.**	**Std. Err.**	**p-val.**	**Magn.**	**Rank**	**Estim.**	**Std. Err.**	**p-val.**	**Magn.**	**Rank**	**Estim.**	**Std. Err.**	**p-val.**	**Magn.**	**Rank**
(Intercept)	-14.467	8.402	0.088			4.368	7.078	0.539			5.517	7.715	0.476		
Male	0.020	0.153	0.894	0.020		0.458	0.129	0.001	0.458	1	0.207	0.141	0.144	0.207	
Age	-0.020	0.004	0.000	0.258	4	0.002	0.003	0.481	0.031		-0.000	0.004	0.994	0.000	
Experience	0.013	0.004	0.002	0.125	9	-0.001	0.003	0.819	0.008		-0.001	0.004	0.751	0.011	
Education 2	-0.195	0.102	0.058	0.195	6	-0.075	0.086	0.384	0.075		0.100	0.093	0.286	0.100	
Generation 2	-0.185	0.088	0.039	0.185	7	0.143	0.074	0.057	0.143	3	0.135	0.081	0.100	0.135	3
Salinity	0.017	0.047	0.728	0.018		-0.015	0.040	0.717	0.015		0.073	0.044	0.096	0.078	4
Temperature	0.109	0.086	0.211	0.046		-0.001	0.073	0.992	0.000		-0.044	0.079	0.578	0.019	
Dissolved Oxygen	-0.002	0.024	0.923	0.005		-0.018	0.020	0.381	0.040		-0.013	0.022	0.560	0.029	
Light penetration	-0.144	0.053	0.008	0.248	5	0.043	0.045	0.338	0.074		-0.052	0.049	0.293	0.089	
Turbidity	0.194	0.067	0.005	0.415	1	-0.016	0.057	0.777	0.034		0.034	0.062	0.582	0.073	
Nitrogen	4.122	2.050	0.047	0.159	8	0.150	1.727	0.931	0.006		-0.387	1.882	0.838	0.015	
Phosphorous	-76.796	30.719	0.014	0.290	2	-14.330	25.880	0.581	0.054		28.570	28.210	0.314	0.108	
Chlorophyll-a	-0.560	0.209	0.009	0.281	3	0.009	0.176	0.961	0.004		-0.126	0.192	0.513	0.063	
pH	1.751	0.981	0.078	0.105	10	-0.212	0.827	0.799	0.013		-0.714	0.901	0.430	0.043	
Eastern Banks	-0.407	0.389	0.297	0.407		0.540	0.327	0.102	0.540		0.700	0.357	0.053	0.700	1
Eastern Bay	0.170	0.261	0.515	0.170		-0.382	0.220	0.085	0.382	2	0.418	0.239	0.084	0.418	2

Model Statistics	**TE**	**UCU**	**Allocative**
Df:	96	96	96
Residual standard error:	0.289	0.243	0.265
Multiple R-squared:	0.469	0.410	0.180
Adjusted R-squared:	0.380	0.311	0.044
F-statistic:	5.292	4.162	1.320
p-value:	0.000	0.000	0.201

Note: Magn. for magnitude

In terms of (unbiased) capacity utilisation, being male and of more than one family generation in the oyster business has a positive and significant impact. In contrast, none of the environmental variables had a significant effect on UCU. This is not surprising, as the measure reflects to a large extent the degree to which output could be increased by increasing variable inputs, all other things being equal. The dummy variables for Eastern Bay (in OLS model) and Eastern Banks (Tobit model only) were significant (Table 6.6 and Table 6.7), suggesting that output of leases in the Eastern Banks (positive coefficient) was more fully utilised than the other areas, while Eastern Bay (negative coefficient) had greatest potential to increase output from increased variable input use.

The results for the allocative efficiency models show that more than one generation in oyster business, average salinity and spatial dummy variables are weakly significant (Table 6.6 and Table 6.7). However, the F-statistic in the OLS model indicates that the variables are not jointly significant, and the very low R-squared coefficient suggest that these factors explain very little of the actual variation in allocative efficiency. Thus, we concluded that the level of allocative efficiency observed in the industry is likely explained by factors other than those assessed in this study.

We did not undertake a second stage analysis on the derived scale efficiency scores. Lease sizes are determined exogenously (by the Government), and are not within the control of the farmers.

6.6 DISCUSSION

Total oyster production in Moreton Bay has declined substantially over recent decades for a variety of reasons, including disease and changing market conditions. The number of active leases in the area, in contrast, has not decreased proportional to the decline in production, suggesting substantial decreases in productivity in the region. The Oyster Industry Management Plan for Moreton Bay Marine Park (QLD DPI&F, 2008a) includes the objectives of increasing production from the existing leases, and measures are available in the related policy on management of non-productive oyster leases (QLD DPI&F, 2007) to potentially confiscate leases that do not meet minimum performance standards.

Given a fixed number of leases, and given that these leases are mostly operated at the optimal scale (from the scale efficiency measures), production can only be increased through either working the leases harder or through increased efficiency. The distribution of capacity utilisation from the analysis suggests that the potential to increase output through greater utilisation is limited for many leases, although a small number of leases were relatively underutilised. In contrast, a high proportion of the leases were operating inefficiently, and improved efficiency is the only way in which total productivity is likely to increase.

The potential to increase efficiency in the area depends on the factors that drive inefficiency, and the degree to which these can be influenced by policy. From the second stage analysis, the key drivers of efficiency differences between farms were largely environmental, and largely related to water quality. Hence productivity improvements are more likely to be improved through improvements in water quality in the region than through activities of individual farmers. Declining water quality has been attributed to substantial degradation of other components of the Moreton Bay marine ecosystem (Jackson *et al.*, 2001), and there is an active program underway to improve water quality through improved catchment management (de la Mare *et al.*, 2012; Pantus & Dennison, 2005). Although oyster farming can be associated with water quality impairments, an assessment of such effect on the water quality in Moreton Bay and subsequent effects on the productivity of the oyster industry was not the scope of this study.

Some farmer specific variables were found to be significant, however, some potential to improve efficiency (and hence production) does exist. The key farmer characteristics that affected the level of efficiency included age, experience, education and family history in the industry. As might be expected, efficiency decreases with the age of farmers but increases with their experience. The fishery is characterised by an older population, many of which enter the industry at a relatively old age (compared with most industries). When comparing these findings with more detailed information about socio-economic characteristics of oyster farmers collected in 2012 (shown in Table 6.2), we can conclude that there is a high degree of hobbyist or lifestyle oyster farmers present in this industry. This type of oyster farmer may have lower incentives in operating their business efficiently than commercial oriented farmers, and thus, this may explain the observed low technical efficiency.

In such a case, efficiency would be enhanced by recruiting younger farmers to the fishery with a greater dependence on the industry for income, but given generally low earnings from the activity and the higher opportunity cost of labour of younger (potential) farmers, due to the co-location with a major city, encouraging younger farmers to the industry is difficult. Given this, the potential requirement of minimum production volumes over a number of years may be counter-productive. While hobbyist or lifestyle farmers could be forced out of industry as a result of the policy, leases that subsequently became available may not necessarily be taken up by existing or new oyster farmers.

The efficiency increase associated with experience suggests that skills can be learnt through time which improves productivity. Understanding these skills and undertaking training may help expedite these productivity benefits. Experience is a common factor affecting efficiency in both wild caught fisheries (Pascoe & Coglan, 2000; Sharma & Leung, 1999; Tingley *et al.*, 2005) and aquaculture (Ahmed *et al.*, 2011; Irz & McKenzie, 2003; Sharma & Leung, 2000).

The result that higher levels of education do not necessarily increase efficiency (and may, in fact, decrease efficiency) is not uncommon in studies of aquacultural efficiency (*e.g.*, Chiang *et al.*, 2004; Onumah *et al.*, 2010), although other studies have found that efficiency levels are related to the level of education (*e.g.*, Dey *et al.*, 2000; Singh *et al.*, 2009). In wild caught fisheries, Pascoe and Coglan (2000) found that education improved the efficiency of vessels using mobile gear (*e.g.*, trawl), but decreased the efficiency of fishers using static gear (*e.g.*, lobster pots). Oyster farming is a largely passive activity, as there is relatively little ongoing intervention required in their husbandry. One possible explanation then is that more educated farmers may be more prone to unnecessarily employing too much labour trying to improve production with less than proportional results. As many of the farmers came to the industry at a more advanced age, another possibility is that more educated farmers came from occupations that involved a very different skill set to those who were less educated.

The outcome for allocative efficiency scores implies that there is the potential for changes in the production mix to enhance production revenues (Figure 6.2, Figure 6.3). However, there was no significant link between observable demographic and environmental factors and the allocative efficiency scores. Key factors that may influence the production mix are the risk of stock loss and the need to maintain of a cash flow. Although oyster farmers would potentially gain a higher price for selling plate (large) sized oysters, this would take a longer than harvesting a smaller size, as SRO take 2.5 and 3.5 years to grown to bistro and plate grade respectively. During this extra year, there is the risk of production loss through diseases, water pollution, extreme weather events or poaching (an ongoing problem in the industry, see Chapter 4.3). More risk averse farmers are likely to harvest a higher proportion of their stock earlier than what otherwise might be considered optimal (Pascoe *et al.*, 2002). Maintaining a cash flow during this period may also be important for farmers, especially those who do not receive a sufficient income from off-farm activities.

6.7 CONCLUSION

The aim of this study was to assess productivity measures such as technical efficiency, scale efficiency, allocative efficiency and capacity utilisation measure for the Moreton Bay SRO industry. We found that there is a relatively low level of technical efficiency in the industry. Some of this can be explained by differences in environmental conditions in Moreton Bay. As such, improvements in water quality in the Bay may result in increased productivity in the industry. However, some demographic traits of the farmers are also significant drivers of efficiency. In particular, the high numbers of pre-retirement hobbyists present in this industry who potentially undertake their oyster business with a low incentive for technical efficient production, and also potentially with the wrong skill set to operate efficiently. Forcing these producers out of the industry through command and control measures (*i.e.,* minimum production requirements) may not be effective in increasing productivity as there are few incentives for younger farmers to enter the industry. Developing appropriate training programs aimed at specific skills may be a more effective means of improving efficiency in the industry.

The following Chapter 7 will investigate the potential impact of climate change and future oyster market dynamics on the economic viability of the SRO industry.

Chapter 7: Impact of climate change and market dynamics on the SRO industry

7.1 INTRODUCTION

Climate change affects primary food producing industries due to their reliance on renewable natural resources. Their productive capacity may vary with changes, for example, in rainfall, temperature and the frequency of extreme weather events. Thus, climate change has implications for food security (Lobell *et al.*, 2008), food markets (Rosenzeig & Parry, 1994) as well as for the economic viability of primary food producing industries and associated livelihoods (Badjeck *et al.*, 2010; Berkes & Jolly, 2001). Hence, adaptation to climate change is important in order to minimise potential future losses in productive capacity and in economic rent; and to maximise the opportunities that climate change may provide primary food producing industries.

The literature provides only a limited range of studies that assess the potential impact of climate change on the productive capacity of aquaculture industries, *e.g.*, Cochrane *et al.* (2009), Hobday *et al.* (2008), and Rosa *et al.* (2012). However, these studies did not assess the potential implications that a change in the productive capacity may mean for the economic viability of aquaculture industries. Furthermore, the role of seafood market dynamics in the sustainability of aquaculture industries under climate change settings has also not been considered in previous studies.

The SRO industry has been affected by severe environmental challenges over the past decade which has significantly affected its production capacity. Furthermore, the emerging Pacific oyster industry in Australia has adversely affected the profitability of the SRO industry (see Chapter 5). Climate change may present additional pressure on the production capacity and economic viability of this industry (Leith & Haward, 2010).

The scientific literature provides a relatively narrow range of studies that investigate factors which may affect the SRO industry's productive capacity under climate change, *e.g.*, Parker *et al.* (2009, 2010, 2011), Parker *et al.* (2012), and Barros *et al.* (2013). The existing body of research focuses on the potential biophysical changes in estuaries that may influence oyster growth and health but does not provide a comprehensive picture of interactions in a complex climate-estuary-industry management relationship.

However, in a survey that was undertaking in 2010, the majority of participating oyster industry members raised concerns about how climate change will impact future oyster production in Australia (Leith & Haward, 2010). While an analysis of the likely economic effects from changing biophysical oyster growing conditions was unavailable, first efforts to identify adaptive strategies of Australia's oyster industry to climate change were undertaken (Leith & Haward, 2010). These included an identification of gaps in the understanding of estuarine systems, their variability from impacts of meteorological events (*e.g.*, rainfall and temperature changes) and human activities (Leith & Haward, 2010). Other adaption strategies identified were the investment in selective breeding programs to develop disease resistance in oysters, improvement of collective action, leadership, communication and need for farmers to engage in industry related decision-making processes. The need for data collection, and monitoring of estuarine health as well as the need for human and financial capital were also raised (Leith & Haward, 2010). However, little of these recognised adaptation areas are reflected in the industry's most recent development strategy (NSW DPI, 2014b).

Despite the complexity and uncertainty associated with identifying the impact of climate change on this industry, there is a need to (1) quantify what the potential changes might mean in economic terms should the industry carry on with business as usual; (2) consider how market dynamics may affect the SRO industry under climate change settings; (3) review the already identified strategies for adaption to climate change and mitigation of potential losses, and (4) adopt adaptation approaches in industry development strategies (adapted from Norman-Lopez *et al.* (2011)).

The aim of this study was to address the first two tasks by assessing the potential impact of climate change and market dynamics on the economic variability of the SRO industry. This corresponds with aim 4 of the research program.

The analysis in this study occurred in four steps. First, we developed a model that integrates biophysical (that is salinity and water temperature) and economic variables to estimate a revenue function for each of the 22 major oyster production estuaries. Secondly, we assessed the sensitivity of industry revenue with respect to biophysical change and output prices based on observed data. Following that, projections for climate change in NSW and Queensland were used to estimate the economic impact of climate change on oyster production capacity and, thus, on the future economic viability of the industry. Lastly, we included possible changes to oyster market dynamics in order to assess the role of markets in potential future climate scenarios. In this study, we focused on the time period of 2030 as future climate is expected to be 'locked in' based on the greenhouse gas emissions to date (IPCC, 2013). This time frame is within the planning horizon for many fisheries (Hobday & Poloczanska, 2010).

The findings from this study provide a baseline against which future industry development strategies and adaptations efforts could be prioritised and evaluated.

7.2 THE ROLE OF SALINITY AND WATER TEMPERATURE FOR OYSTER GROWTH

SROs grow in estuaries and important determinants that affect growth and health of SROs in these ecosystems are salinity and water temperature (hereafter referred to as temperature) as well as combinations of these (Dove & O'Connor, 2007; Holliday, 1995; Nell & Holliday, 1988; Parker *et al.*, 2009, 2010; Rowse & Fleet, 1984). Salinity and temperature are vital factors as they affect physiology, stages of development and distribution of oysters (Dove & O'Connor, 2007; Shumway, 1996). It has also been shown that low salinity levels can negatively affect the immune system of SROs which may make them more susceptible for disease such as the QX disease (Butt *et al.*, 2006).

Optimal salinity and temperature levels for oyster growth are summarised in Table 7.1, as well as tolerance ranges which vary depending of the development stage of oysters. In controlled laboratory experiments the optimal salinity and temperature combination for larvae was found at 27-39 ppt and 26-30 °C (Dove & O'Connor, 2007; Nell & Holliday, 1988); and for spat 35 ppt and 30 °C (Dove & O'Connor, 2007). This shows that SROs optimally function within a narrow salinity and temperature range. Rubio Zuazo (2008) showed that SROs can only tolerate extreme salinities for a limited period of time and that a low level of salinity compromises the development and growth of oysters as oysters stop feeding.

Table 7.1: Salinity and temperature ranges for optimum growth and tolerance levels

Determinates	Development stage		
	Larvae	**Spat**	**Adult**
Salinity optimum (ppt)	23-39[#, *,^]	20-40[#,*,^]	23-35[#]
Salinity tolerance (ppt)	15-39[#]	0-41[#]	0-50[#]
Temperature optimum (°C)	19-30[#,^]	14-30[#,^]	18-26[#]
Temperature tolerance (°C)	N/A	11-30[#]	11-30[#]

Sources: [#] Holliday (1995), *Nell and Holliday (1988), ^Dove and O'Connor (2007).

Other factors that affect oyster growth include the level of nutrient supply, oxygen level, pH level, presence of algae blooms, diseases such as QX disease, winter mortality; and other aspects (*e.g.*, Butt *et al.* (2006), Green and Barns (2010b), Paterson *et al.* (2003), Smith *et al.* (2000) and Parker *et al.* (2009)).

Changes in the pH level of estuarine water are of particular interest in the assessment of how climate change may affect the oyster industry. This is the case because increasing ocean acidification (decrease in pH level) due to anthropogenic climate change may have negative implications on oyster larvae development (Parker *et al.*, 2009, 2010; Parker *et al.*, 2012) and consequently the productive capacity of the industry. Unfortunately, there was no data available for observed pH levels in all oyster producing estuaries and therefore the variable pH had to be excluded from the analysis is this study.

7.2.1 Salinity, temperature and climate change predictions

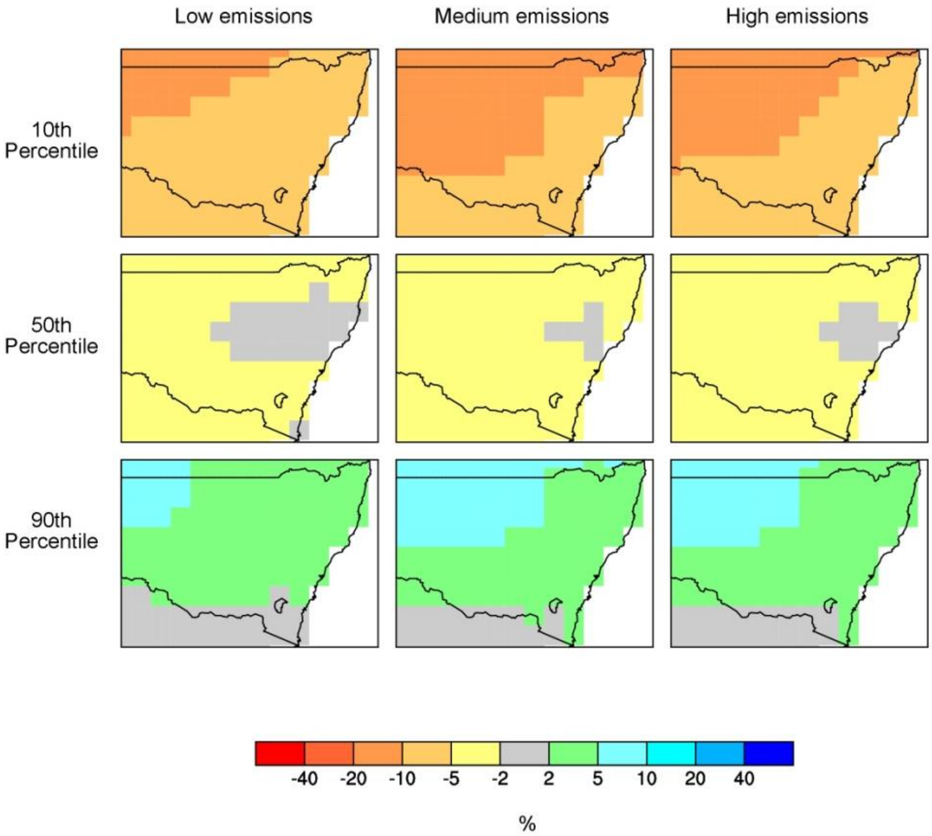
Salinity levels and the distribution of salinity within estuaries depend on a range of factors, such as water depth, tidal currents that generate turbulences, wind, freshwater and sediment inflows from rivers, marine water supplies by exchange with oceans and evaporation rates (Heap *et al.*, 2001). Freshwater discharge in estuaries is mainly seasonal and controlled by the catchments conditions including rainfall patterns (Hardisty, 2008). The inflow of marine water in the NSW and Queensland estuaries is mainly driven by wave-dominated (mostly southern NSW) and tide-dominated (northern NSW and Queensland) inflow regimes (Heap *et al.*, 2001). Observed salinity levels in these estuaries typical range from 0 ppt (fresh) to 38 ppt (Healthy Waterways Ltd, 2012; NSW Food Authority, 2012).

Estimations for future changes in estuary salinity levels along the NSW and Queensland coasts were unavailable. However, a proxy for changes in coastal sea water salinity can be derived based of the relationship between salinity (S), evaporation (E) and precipitation (P). This relationship can be described as $S = E - P$, that is changes in ocean salinity can be expressed by fluxes in evaporation and precipitation (*e.g.*, Badjeck *et al.* (2010), Yu (2011) and Josey *et al*. (2013)). Yet, as projections for evaporation were also unavailable, we used estimates for expected changes in evapotranspiration[20]. The predicted annual changes in evapotranspiration and changes in annual precipitation are shown in Figure 7.1 and Figure 7.2 (CSIRO & Bureau of Meteorology, 2007)

Changes in precipitation are not directly influenced by rising greenhouse gases. However, a warmer atmosphere, caused by increasing greenhouse gases, can hold more water vapour, and thus can produce heavier precipitation (CSIRO & Bureau of Meteorology, 2007). Furthermore, changing temperature patterns across the planet imply that the wind patterns may change the rainfall patterns (CSIRO & Bureau of Meteorology, 2007). The predicted annual change in rainfall for 2030 (see Figure 7.1) indicates that low, medium and high emission scenarios will likely lead to similar effects.

[20] Evapotranspiration is the sum of evaporation and plant transpiration from the earth's land surface (evaporation) to the atmosphere.

Figure 7.1: Predicted annual change in rainfall 2030 (NSW)

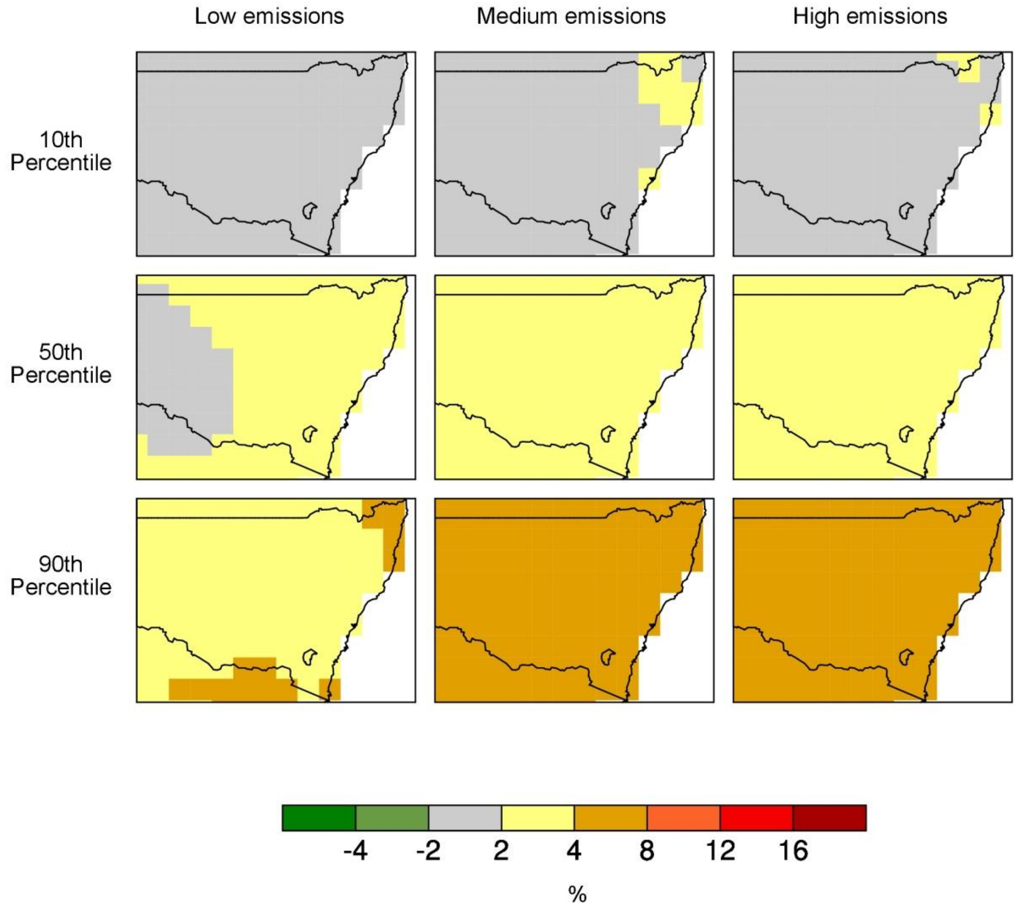


Notes: The projections give an estimate of the average climate around 2030. Individual years may show variation from this average. The 50th percentile (the mid-point of the spread of model results) provides a best estimate result. The 10th and 90th percentiles (lowest 10 per cent and highest 10 per cent of the spread of model results) provide a range of uncertainty. Emission scenarios are from the IPCC Special Report on Emission Scenarios (IPCC, 2000). Low emissions is the B1 scenario, medium is A1B and high is A1FI (IPCC, 2000). Source: CSIRO and Bureau of Meteorology (2007).

The best estimate (50th percentile) for all emission scenarios in Figure 7.1 shows that annual rainfall will likely decrease in southern parts of NSW while rainfall patterns may remain unchanged in the northern parts of NSW and Queensland. However, the extent of changes to annual precipitation by 2030 shows a large spread, ranging from annual change of around -20 per cent to +5 per cent in the 10th (most negative) and 90th (most positive) percentile respectively (CSIRO & Bureau of Meteorology, 2007). This suggests a high level of uncertainty about future changes in precipitation.

Annual evapotranspiration for NSW in 2030 is likely to increase by up to 4 per cent in the best estimate (Figure 7.2) and up to 8 per cent in the highest spread estimate (CSIRO & Bureau of Meteorology, 2007).

Figure 7.2: Potential annual evapotranspiration 2030 (NSW)



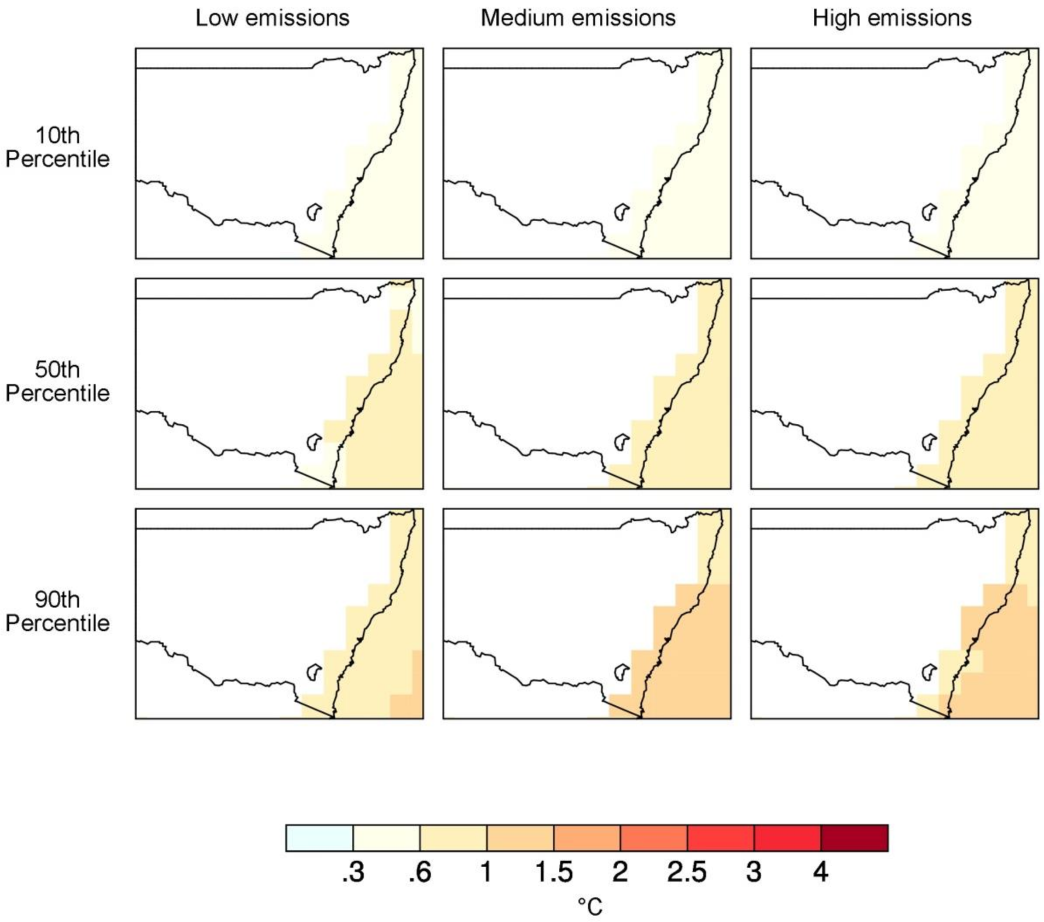
Note: See notes for Figure 7.1. Source: CSIRO and Bureau of Meteorology (2007).

More details about how the proxy data for estuary salinity was derived from the available projections for evapotranspiration and rainfall will be outlined in the following section 7.3.

The second variable that we used in our analysis is temperature. The temperature of estuarine waters varies on daily and seasonal time scales (Hardisty, 2008). It also varies spatially, depending upon the relative temperatures of the tidal and freshwater inputs (Hardisty, 2008). In temperate latitudes, fresh-water is usually colder than the seawater in winter which provides a positive temperature gradient in a seaward direction and toward high water (Hardisty, 2008). On the other hand, freshwater is warmer than the seawater in summer, with gradients operating in the opposite direction (Hardisty, 2008). The typical temperature observed in the NSW and Queensland estuaries ranges from 10 °C to 30 °C (Healthy Waterways Ltd, 2012; NSW Food Authority, 2012).

Estimations for changes in annual estuary temperatures were also unavailable. The closest proxy for temperature in estuaries was the coastal sea surface temperature projected for the region which is illustrated in Figure 7.3. This figure shows that the sea surface water temperature in this region is estimated to increase by +0.3 to +1.5°C by 2030 relative to the period 1980-1999 (see Figure 7.3, CSIRO and Bureau of Meteorology (2007)).

Figure 7.3: Predicted annual sea surface temperature change 2030 (NSW)



Note: See notes for Figure 7.1. Source: CSIRO and Bureau of Meteorology (2007).

The sea surface temperature projections for the low, medium and high emission scenarios vary only minor between the 10th and 50th percentile estimation. The major difference in the emission scenarios was found in the 90th percentile. This implies, particularly for the medium and high emission scenarios, a presence of a relatively large level of uncertainty about potential changes in sea surface water temperature.

In summary, the projections for climate change indicate that oyster production in NSW and Queensland estuaries will be likely facing highly variable annual precipitation patterns, increasing annual evapotranspiration and increases in sea surface temperature. The effect of these variables on the economic sustainability of the SRO industry was analysed in the remainder of this study.

7.2.2 Recap of findings about Australia's oyster market

In Chapter 5 we undertook an analysis of the market and demand for oysters in Australia. We found that the market share of the SRO in terms of production volume has significantly decreased in the past decade. The Pacific oyster is now holding the major share in Australia's oyster market with about 70 per cent of oyster production by volume.

We showed that prices of the largest oyster producing States for each species, NSW and South Australia, hold a long-run relationship. However, the results in Chapter 5 suggested that the oysters sold in NSW and South Australia were not perfect substitutes and we concluded that the market in these States and, thus, for the two oyster species, are not fully integrated.

An analysis of the demand for oysters revealed that changes in the SRO supply have little effect on the price of SROs (see Chapter 5). Yet, changes in the supply of Pacific oysters may have had a large effect on the price for Pacific oysters. This suggested that Pacific oysters face a relatively elastic demand, more so than the demand for SROs. We also found that changes in the quantities supplied of Pacific oysters had a significant impact on the price formation of SROs but not vice versa.

The knowledge about the market relationship of Australia's major commercial oyster species was used in this study to assess the role of market settings in the potential economic viability of the SRO industry under climate change scenarios.

7.3 METHOD AND DATA

In this study we investigated the potential impact of climate change and market settings on the revenue of the SRO industry. We chose to study the revenue of the industry due to the unavailability of production cost data, which limits an investigation of the industry's current and future profitability. However, changes to the revenue or income of an industry, assuming constant production cost, can provide sufficient information about the industry's potential future economic sustainability. This appears to be an appropriate assumption according to Diewert (1974) and Shephard (1970) who claimed that revenue maximisation is equivalent to profit maximisation when all inputs are fixed.

Revenue functions have been applied in the context of fisheries in a range of previous studies, *e.g.*, Kirkley and Strand (1988), McIlgorm (1995), Asche (2009) and Thunberg *et al.* (1995).

Diewert (1974) defined a revenue function (*R*) as the function that returns the maximum revenue for an exogenous output price vector (*p*), given a fixed input vector (*x*), and technical constraints:

$$R(p,x) = max_y\big(p'y : y \in L(x)\big) \tag{7.1}$$

where *y* is an output vector and *L(x)* is the firm's output possibility set given the inputs *x*. The revenue function is a convex and continuous function in *p* and, hence, it is positively linear homogeneous on *p* for every $x \geq 0$. The revenue maximising supply function can be derived from a first order partial derivative of the revenue function with respect to output prices (Diewert, 1974):

$$y_i(p,x) = \frac{\partial R(p,x)}{\partial p_i} \tag{7.2}$$

We considered this basic definition to develop the revenue function for the analysis in this study. The determination of the true functional form of a given relationship is impossible (Griffin *et al.*, 1987). In this study, we chose a translog revenue function (*R*) as an approximation for oyster production in each estuary (*r*) in each year (*y*):

$$\begin{aligned}\ln R_{r,y} = \beta_0 + &\sum_g \beta_g \ln p_{r,g,y} + \frac{1}{2}\sum_{g1}\sum_{g2} \beta_{g1,g2} \ln p_{r,g1,y} \ln p_{r,g2,y} \\ &+ \sum_i \beta_i \ln I_{r,i,y} + \frac{1}{2}\sum_{i1}\sum_{i2} \beta_{i1,i2} \ln I_{r,i1,y} \ln I_{r,i2,y} \\ &+ \sum_g\sum_i \beta_{g,i} \ln p_{r,g,y} \ln I_{i,i,y} + \sum_d \beta_d \ln D_d \end{aligned} \tag{7.3}$$

where *p* is an output price vector for the three product grades (*g*) large (plate), medium (bistro) and small (bottle), *I* is an input vector including the (aggregated) hectares farmed, number of business entities (farmers), average annual temperature and average annual salinity in each estuary; and D are dummy variables that include estuary specific data.

The translog functional form is commonly used in the production economics literature and in a fisheries context (*e.g.*, Asche, 2009; Bukenya *et al.*, 2013; Gordon, 1989 ; Hanson *et al.*, 2001; Thunberg *et al.*, 1995). It provides a generalisation of the Cobb-Douglas function since given $\beta_g > 0$ for all β_g, $\beta_{g1,g2} = 0$ for all g_1 and g_2, $\beta_{i1,\, i2} = 0$ for all i_1 and i_2, $\beta_{g,i} = 0$ for all g and all i the translog form will collapse into a Cobb-Douglas form. Yet, unlike the Cobb-Douglas form the translog does not restrict the values of the elasticity of substitution to vary with the level of output and/or input proportions (Corbo & Meller, 1979). The flexible properties of the translog functional form were assumed to be appropriate for the analysis in this study. Translog revenue functions were previously applied on fisheries by Asche (2009) and Thunberg *et al.* (1995).

Based on Hotelling's lemma, the revenue maximising supply function for each grade (g) is given by:

$$S_g = \beta_{g1} + \sum_{g2} \beta_{g1,g2} \ln p_{r,g2,y} + \sum_{i} \beta_{g1,i} \ln I_{r,i,y} \qquad (7.4)$$

where S_g is the revenue share of grade g.

The revenue function model and associated share equations need to be estimated simultaneously as a system of equation with a generalized least squares estimator. This approach takes the covariance structure of the residuals into account. This estimation procedure is generally called seemingly unrelated regression and was first described by Zellner (1962).

A further reason to estimate a system of equations simultaneously is that cross-equation restrictions on the coefficients are required to ensure theoretical consistency. For example, symmetry in process is imposed by linear homogeneity (constant returns to scale) in prices is imposed on the revenue function by:

$$\sum_{g,i=T,S} \beta_{g,i=T,S} = 1, \sum_{g1} \beta_{g1,g2} = \sum_{g1} \beta_{g1,i} = 0 \qquad (7.5)$$

where T is the production input temperature and S the input salinity.

Differentiating the translog revenue function (equation 7.3) with respect to the price of each oyster grade, and the inputs (salinity and temperature) respectively, yields the following expressions:

$$\frac{\partial \, ln \, R_{r,y}}{\partial \, ln \, p_{g1}} = \beta_{g1} + \sum_{g2} \beta_{g1,g2} \ln p_{r,g2,y} + \sum_{i} \beta_{g1,i} \ln I_{r,i,y} \qquad (7.6)$$

$$\frac{\partial \, ln \, R_{r,y}}{\partial \, ln \, I_{i=T}} = \beta_{i=T} + \sum_{i \neq T} \beta_{\, i=T} \, ln \, I_{i \neq T} + \sum_{g} \beta_{g,i=T} \ln p_{r,g,y} \qquad (7.7)$$

These represent the price and input revenue elasticities[21].

Only significant coefficients from the estimation for the revenue functions were used to estimate the respective elasticities. These expressions (7.6 and 7.7) represent single variable effects that affect the revenue in each estuary.

In this study we first analysed the relationship between temperature, salinity, product prices and observed revenue of the industry using equations (7.6) and (7.7) and available production and environmental data sets. We then used the same equations to investigate how predicted changes to temperature and salinity ($\Delta \, I$) and hypothetical changes to prices of the goods ($\Delta \, p_g$) may affect the revenue of this industry.

Production data

For the analysis we used aggregated production data for all major SRO producing estuaries in Queensland (Wingfield & Heidenreich, 2013) and NSW (NSW DPI, 2013a). Information on oyster production in estuaries with five or less producers as well as individual oyster farm data were unavailable due to privacy restriction on the NSW data. The final panel data set contained annual records covering the period 2003-2012. Included in the data set were production outputs in three different grades (sizes) of oysters as well as the value of these quantities from which we derived the output prices. Also available was the total annual hectare size allocated to oyster production in each estuary, and total number of oyster business entities (hereafter referred to as farmers) in each estuary in each year. We used dummy variables to capture other physical and geographic characteristics of the individual estuaries.

[21] The revenue elasticity equation (7.6) is equivalent to the revenue share equation (7.4).

Monthly records for salinity and water temperature in each NSW estuary was provided by the NSW Food Authority for the period 2003-2012 (NSW Food Authority, 2012). Similar data for the Moreton Bay oyster production area in Queensland was provided by Healthy Waterways Ltd. (2012). Although there were more environmental variables available and records dating back to 2000 for the Queensland oyster production area, no such information exists for all NSW estuaries. Based on the available monthly observations we derived annual average values for salinity and water temperature in each estuary. A summary of the mean values for these variables over the period 2003-2012 is shown in Table 7.2. For the analysis the values for all variables were logged.

Table 7.2: Descriptive statistics (period 2003-2012), mean values

Estuary	**Revenue***	**Bottle***	**Bistro***	**Plate***	**Area**	**Farmer**	**Temp.**	**Sal.**
Moreton Bay	499,030	3.32	5.19	7.05	425	67	22.48	25.84
Tweed River	359,985	3.69	5.24	6.97	21	6	25.08	25.66
Bellinger River	338,265	3.48	4.97	6.68	25	6	22.11	23.05
Nambucca River	586,415	4.01	5.67	7.47	63	10	21.65	25.89
Macleay River	447,334	4.01	5.67	7.47	79	19	22.85	27.02
Hastings River	1,436,498	4.01	5.67	7.47	113	31	22.16	27.15
Camden Haven River	1,227,219	4.01	5.67	7.47	95	15	20.27	29.56
Manning River	915,748	4.13	5.67	6.81	206	25	20.23	22.56
Wallis Lake	11,053,187	4.01	5.67	7.47	346	30	21.02	31.61
Port Stephens	4,272,320	4.01	5.67	7.47	624	60	19.46	29.14
Hunter River	141,746	3.36	4.73	6.40	22	8	19.25	27.21
Brisbane Water	1,761,019	4.01	5.64	7.47	127	37	20.06	30.63
Hawkesbury River	1,279,944	3.74	5.56	7.33	284	18	20.47	25.75
Shoalhaven River	271,014	3.76	5.32	7.06	13	6	18.93	27.36
Crookhaven River	604,561	4.15	5.67	7.47	134	15	18.88	34.79
Clyde River	4,094,036	4.01	5.67	7.47	189	25	18.74	27.41
Tuross River	329,934	4.01	5.67	7.47	98	12	18.31	27.97
Wagonga Inlet	1,274,300	4.09	5.81	7.62	81	17	18.92	32.65
Wapengo Lagoon	401,707	4.09	5.81	7.62	71	12	17.18	32.74
Merimbula Lake	1,343,234	4.01	5.67	7.47	126	17	17.73	32.68
Pambula River	1,019,888	4.01	5.67	7.47	98	26	18.61	32.00
Wonboyn River	330,435	4.01	5.67	7.47	49	13	17.20	36.86

Notes: * in Australian Dollars, Bottle for bottle price (smallest grade), Bistro for bistro price (medium grade), and Plate for plate price (large grade), Temp. for temperature, Sal. for salinity.

Climate change data

In order to simulate climate change conditions for estuaries along the Queensland and NSW coast, we used projections for changes in annual sea surface temperature and annual precipitation for 2030 relative to the period 1980-1999 (see Figure 7.1 and Figure 7.3 (CSIRO & Bureau of Meteorology, 2007)). Since projections for evaporation were unavailable, which is required to derive estimates for changes in salinity levels (S = E – P), we used the available estimates for annual evapotransiration (Figure 7.2).

A proxy for changes in sea water salinity was derived based on its relationship with evaporation (evapotransiration) and precipitation as described for example by Yu (2011) (see Section 7.2.1). Our assumptions about salinity changes were broadly in line with global estimations by Yu (2011) and Josey *et al.* (2013) who showed that ocean surface salinity on the eastern Australian coast is likely to become more saline. The assumptions for average changes in sea surface temperature and the derived average changes in salinity (Table 7.3) were based on predictions shown in Figure 7.1, Figure 7.2 and Figure 7.3.

Since the reference period (1980-1999) of these predictions has already passed, we accounted for that by assuming that the changes were and are occurring on a gradual, annual rate and adjusted the predicted average change rates and absolute values up until 2012 which was treated as reference year in the analysis. The time adjusted values for changes in salinity and sea surface temperature are shown in brackets in Figure 7.3. We used these time adjusted values in our analysis.

Table 7.3: Average changes in climate related variables

Percentile	Salinity change (S) (Absolute range: +18% to +2%)		
	Low	Medium	High
10%	7.5 [3.25]	13.5 [5.85]	8.5 [3.68]
50%	4.5 [1.95]	4.5 [1.95]	4.5 [1.95]
90%	3.5 [1.52]	2.5 [1.08]	2.5 [1.08]
Percentile	**Precipitation change (P)** (Absolute range: -20% to +5%)		
	Low	**Medium**	**High**
10%	-7.5	-12.5	-7.5
50%	-1.5	-1.5	-1.5
90%	1.5	3.5	3.5
Percentile	**Evapotranspiration change (E)** (Absolute range: -2% to + 8%)		
	Low	**Medium**	**High**
10%	0	1	1
50%	3	3	3
90%	5	6	6
Percentile	**Sea surface temperature change** (Absolute range: +0.3°C to +1.5°C)		
	Low	**Medium**	**High**
10%	0.45 [0.26]	0.45 [0.26]	0.45 [0.26]
50%	0.80 [0.45]	0.80 [0.45]	0.80 [0.45]
90%	0.80 [0.45]	1.05 [0.60]	1.05 [0.60]

Note: Average values for changes in precipitation, evapotranspiration and sea surface temperature were derived based on estimation in CSIRO and Bureau of Meteorology (2007) (see Figure 7.1, Figure 7.2 and Figure 7.3). The change in salinity was derived from average evapotranspiration and average precipitation estimates (S=E-P). These are average annual changes for 2030 relative to the reference period 1980-1999. Time adjusted values are shown in brackets.

Market settings

The study presented in Chapter 5 found that that SRO prices are relatively inelastic to changes in quantities supplied in the long-run. However, we assumed here that the output prices may cyclically adjust due to the law of demand but that SRO prices will not be affected by changes in its own output volume in the period to 2030.

In Chapter 5 we also showed that the cross-price flexibility between SRO and Pacific oysters is -0.147, which implies that a small change in the supply of Pacific oysters may have a high impact on SRO prices. We have also shown that there is no such dynamic observable for changes in SRO supply on Pacific oyster prices. We used this knowledge for our analysis in equation (7.4) and assume that this market relationship between the two major commercial oyster species in Australia will remain constant over time.

Since there is an observed negative relationship between the supply of Pacific oysters and prices of SROs, an assumption about the future supply of Pacific oysters was required for our analysis. Although the literature suggests that the Pacific oyster may also be negatively affected by climate change (*e.g.*, Timmins-Schifferman *et al.* (2011), Timmins-Schifferman *et al.* (2013), Clark *et al.* (2013) and Barros *et al.* (2013)) an analysis that focuses on the effect of environmental change on the productive capacity of the Pacific oyster industry has not yet been undertaken.

In the absence of such information we assumed that the supply of Pacific oyster may vary in 2030 by between -10 per cent, 5 per cent and 24 per cent compared to its current production volume. We based the highest growth assumption for Pacific oyster supply on observed production volume for the period 2008-2012 (ABARE-BRS, 2010; ABARES, 2013), during which the supply of Pacific oysters increased by 24 per cent. The lower hypothetical thresholds of a -10 per cent decrease and a 5 per cent increase in Pacific oyster production volume assumed a relatively pessimistic outlook for this industry.

We assumed that all production inputs and costs remain constant. The same was assumed for the demand of oysters in Australian, general seafood market settings, as well as the management and regulatory framework of the SRO industry in our analysis.

Scenarios

In our analysis we focused on three climate scenarios, that are LOW 10, LOW 50 and HIGH 90 (see CSIRO and Bureau of Meteorology (2007)). The LOW 10 represents the low emission scenario with least informed average projections (10th percentile, see Table 7.3). As a best case scenario we used the average low emission scenario predictions for the 50th percentile (see Table 7.3). The extreme climate scenario was based on average predictions for the 90th percentile of the high emission climate change scenario (see Table 7.3). We applied the time adjusted average predicted changes (see Table 7.3, values in brackets) to the observed annual salinity and temperature data for each of the 22 estuaries to estimate future climate scenarios based on equation 7.7.

Market scenarios that assume that the supply of Pacific oyster may vary in 2030 by either -10 per cent, 5 per cent and 24 per cent compared to its observed production volume, were then added to the findings of the climate change scenarios.

7.4 RESULTS

We estimated the revenue function (equation 7.3) and obtained the results shown in Appendix C. The obtained revenue estimation has an adjusted R-square of 0.86, indicating that a large proportion of the variation in revenue is explained by the chosen independent variables (see Table 7.A in Appendix C). It should also be highlighted that all three price variables were highly correlated which may affect reliability of the all price related results in this study.

Based on the obtained significant coefficients in the estimation of the revenue function we derived observed revenue elasticities with respect to prices (see equation 7.6), salinity and temperature (see equation 7.7). For example, to derive the revenue elasticity with respect to temperature from the results in Table 7.A in Appendix C the following coefficients were used: 'Temperature squared', 'Farmers and temperature' and 'Temperature and salinity'. These coefficients were then multiplied with the normalized mean value for the respective single or interaction-term variable. The results are presented in Table 7.4.

Table 7.4: Revenue elasticities

Estuary	Temperature			Salinity			Plate price			Bistro price			Bottle price		
	Elasticity	Std. Error	p-value	Elasticity	Std. Error	p-value	Elasticity	Std. Error	p-value	Elasticity	Std. Error	p-value	Elasticity	Std. Error	p-value
Moreton Bay	1.290	0.932	0.169	0.214	0.451	0.635	0.297	0.016	0.000	0.318	0.101	0.002	0.3071	0.0107	0.0000
Tweed River	-3.353	1.102	0.003	-2.721	0.700	0.000	0.374	0.016	0.000	0.356	0.098	0.000	0.3257	0.0040	0.0000
Bellinger River	-1.594	0.953	0.098	-1.872	0.549	0.001	0.370	0.017	0.000	0.355	0.098	0.000	0.3143	0.0079	0.0000
Nambucca River	-1.274	0.569	0.027	-1.030	0.263	0.000	0.358	0.009	0.000	0.348	0.056	0.000	0.3251	0.0016	0.0000
Macleay River	-1.037	0.453	0.023	-1.162	0.280	0.000	0.339	0.002	0.000	0.337	0.003	0.000	0.3251	0.0016	0.0000
Hastings River	-0.017	0.477	0.967	-0.715	0.193	0.000	0.323	0.006	0.000	0.328	0.038	0.000	0.3251	0.0016	0.0000
Camden Haven River	-0.814	0.212	0.000	-0.347	0.092	0.000	0.350	0.004	0.000	0.341	0.023	0.000	0.3251	0.0016	0.0000
Manning River	1.498	0.437	0.001	0.253	0.174	0.149	0.324	0.006	0.000	0.331	0.018	0.000	0.3284	0.0034	0.0000
Wallis Lake	-0.448	0.372	0.228	0.439	0.350	0.211	0.330	0.006	0.000	0.329	0.035	0.000	0.3251	0.0016	0.0000
Port Stephens	1.766	0.758	0.021	1.326	0.528	0.013	0.305	0.015	0.000	0.317	0.092	0.001	0.3251	0.0016	0.0000
Hunter River	-0.890	0.651	0.174	-1.194	0.553	0.033	0.368	0.013	0.000	0.350	0.078	0.000	0.3124	0.0103	0.0000
Brisbane Water	0.465	0.440	0.287	-0.065	0.033	0.052	0.323	0.008	0.000	0.325	0.052	0.000	0.3254	0.0016	0.0000
Hawkesbury River	0.141	0.231	0.545	0.436	0.279	0.121	0.339	0.003	0.000	0.340	0.009	0.000	0.3180	0.0029	0.0000
Shoalhaven River	-1.144	0.819	0.167	-1.471	0.711	0.041	0.376	0.016	0.000	0.356	0.098	0.000	0.3205	0.0027	0.0000
Crookhaven River	-1.093	0.381	0.005	0.322	0.078	0.000	0.357	0.006	0.000	0.340	0.024	0.000	0.3289	0.0037	0.0000
Clyde River	1.109	0.234	0.000	0.624	0.166	0.000	0.331	0.003	0.000	0.332	0.019	0.000	0.3251	0.0016	0.0000
Tuross River	0.030	0.425	0.944	0.250	0.135	0.066	0.356	0.007	0.000	0.346	0.044	0.000	0.3251	0.0016	0.0000
Wagonga Inlet	-0.542	0.253	0.034	-0.080	0.145	0.580	0.350	0.003	0.000	0.340	0.012	0.000	0.3264	0.0030	0.0000
Wapengo Lagoon	-0.199	0.559	0.721	0.366	0.276	0.187	0.361	0.007	0.000	0.345	0.040	0.000	0.3264	0.0030	0.0000
Merimbula Lake	0.080	0.379	0.833	0.624	0.172	0.000	0.349	0.003	0.000	0.339	0.010	0.000	0.3251	0.0016	0.0000
Pambula River	0.370	0.304	0.225	0.158	0.114	0.169	0.336	0.004	0.000	0.332	0.023	0.000	0.3251	0.0016	0.0000
Wonboyn River	-0.778	0.633	0.220	0.079	0.359	0.825	0.363	0.008	0.000	0.344	0.035	0.000	0.3251	0.0016	0.0000

Note: Estimation of revenues elasticities based on equation (7.6) and (7.7) and observed data during the period (2003-2012).

The results for the revenue elasticities in Table 7.4 show that the revenue in some estuaries may have been negatively affected by changes in temperature and salinity in the past, while the opposite effect was observed for other estuaries. We found a relatively large difference in the absolute values of revenue elasticities for both, temperature and salinity. This implies that the observed revenues responded either relatively elastic or relatively inelastic to past environmental fluctuation depending on other characteristics of the estuaries.

The positive temperature effect on revenue in estuaries such as Moreton Bay, Manning River, Port Stephens and Clyde River can be explained by the relatively large number of farmers present (see Table 7.2) in these estuaries and structure of our model (equation 7.3 and 7.6, Table 7.A in Appendix C)[22]. This result suggests that the number of farmers in an estuary played a significant role in how water temperature affected the revenue in the production areas in the past. This result implies further that the management of environmental changes, such as change in temperature, may affect the economic profitability of the industry.

The result for the effect of salinity on the industry revenue in Table 7.4 is mainly driven by estuary size and temperature (see Table 7.2 and Table 7.A in Appendix C). This finding suggests that production in larger estuaries may have been better able to respond to changes in salinity than production in smaller areas in the past.

Our results also show that the industry's revenue is relatively inelastic to changes in output prices of any particular grade since all revenue elasticities with respect to oyster prices are less than 1 in absolute terms (see Table 7.4). However, prices are likely to move together, and a restriction of linear homogeneity in terms of prices was also included in the model during its estimation. That is, a 1 per cent increase in price across all three grades results in a 1 per cent increase in revenues, *ceteris paribus*.

When comparing the elasticities of all variables (Table 7.4) it can be seen that in most cases the biophysical variables have a larger impact on revenue than price variables in absolute terms.

[22] Although the elasticity for Moreton Bay was not significantly different from zero.

Based on the findings for observed revenue elasticities we estimated the effect of predicted changes in salinity and temperature as well as potential change in the supply of Pacific oysters on the revenue for the SRO industry.

The results for the climate change scenarios only are shown in Table 7.5.

Table 7.5: Estimated changes to revenue due to climate change

Estuary	LOW 10	LOW 50	HIGH 90
Moreton Bay	1.528%	1.536%	1.541%
Tweed River	-6.224%	-6.203%	-6.191%
Bellinger River	-3.563%	-3.545%	-3.534%
Nambucca River	-2.363%	-2.357%	-2.353%
Macleay River	-2.259%	-2.248%	-2.241%
Hastings River	-0.762%	-0.750%	-0.742%
Camden Haven River	-1.186%	-1.188%	-1.190%
Manning River	1.780%	1.790%	1.797%
Wallis Lake	0.005%	-0.007%	-0.015%
Port Stephens	3.171%	3.166%	3.163%
Hunter River	-2.146%	-2.135%	-2.127%
Brisbane Water	0.403%	0.409%	0.413%
Hawkesbury River	0.597%	0.591%	0.587%
Shoalhaven River	-2.692%	-2.679%	-2.670%
Crookhaven River	-0.772%	-0.789%	-0.800%
Clyde River	1.775%	1.775%	1.776%
Tuross River	0.291%	0.287%	0.285%
Wagonga Inlet	-0.633%	-0.637%	-0.640%
Wapengo Lagoon	0.180%	0.172%	0.166%
Merimbula Lake	0.732%	0.722%	0.715%
Pambula River	0.539%	0.540%	0.541%
Wonboyn River	-0.707%	-0.717%	-0.724%

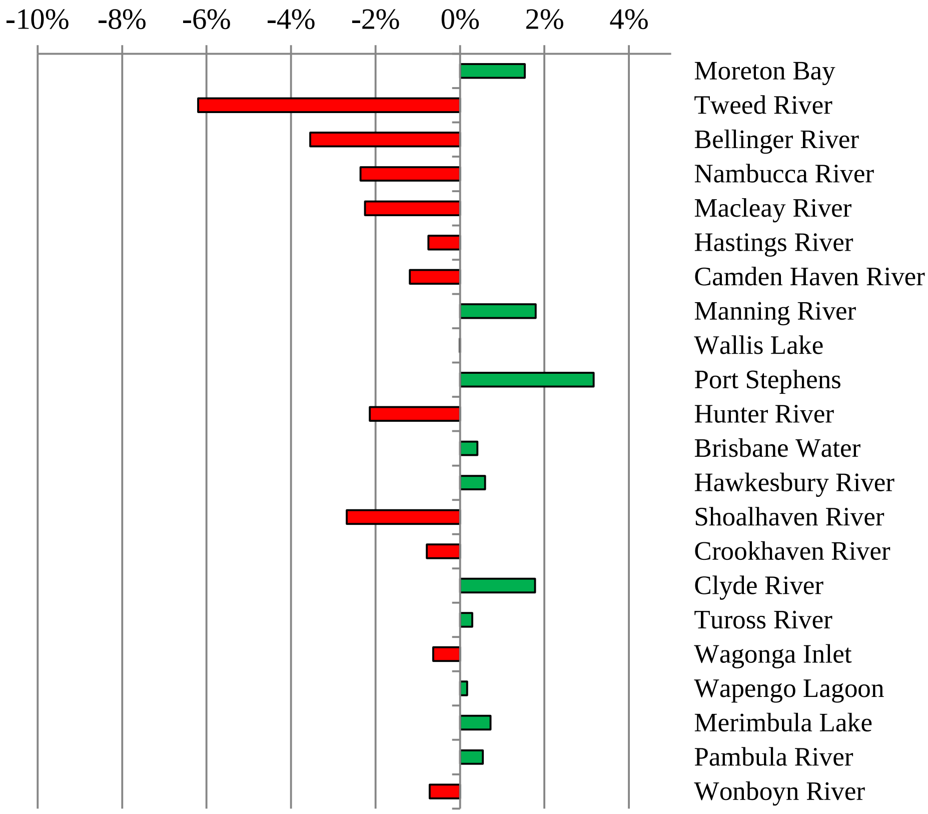
Note: In the chosen colour scheme red represents a negative, green a positive and yellow a relative neutral impact of changes in temperature and salinity on the revenue of oyster production.

The results suggest that there may only be minor difference in the impact of changing salinity and temperature on the industry's future revenues (Table 7.5) between the three climate scenarios. The results in Table 7.5 also suggest that the climate change impact on the industries' revenue may only be moderate ranging, for example, from a loss of about 6.22 per cent to an increase of approximately 3.17 per cent in the LOW 10 scenario.

The simulation outcome for all climate change scenarios suggests further that the future revenue of oyster farming may vary depending of the production area (see

Table 7.5). The results for the LOW 50 scenario (Table 7.5) illustrates that some areas may experience an increase in revenue, while others may be facing a loss.

Figure 7.4: Results for climate change scenarios LOW 50



This finding is primarily driven by the observed revenue elasticity for temperature and salinity (see Table 7.4) which provided the foundation for simulating the combined effect of future changes in temperature and salinity on the industry's revenue. This central relationship between revenue and the two environmental variables was assumed to remain constant and is therefore reflected in results of future revenue estimations.

The estimations for changes in the industry revenues due to changes in the supply of Pacific oysters is shown in Table 7.6. Based on the established negative relationship between the supply of Pacific oysters and prices for SROs, the revenue of the SRO industry under hypothetical future scenarios may be adversely affected by increases in Pacific oyster production (see Table 7.6). A more positive market effect on the revenue of all SRO producing estuaries could be observed if the supply of Pacific oysters would diminish further than here assumed in future.

Table 7.6: Estimated changes to revenue due to market dynamics

Estuary	PO supply +5%	PO supply +24%	PO supply -10%
Moreton Bay	-0.68%	-3.25%	1.36%
Tweed River	-0.78%	-3.72%	1.55%
Bellinger River	-0.76%	-3.67%	1.53%
Nambucca River	-0.76%	-3.64%	1.52%
Macleay River	-0.74%	-3.53%	1.47%
Hastings River	-0.72%	-3.45%	1.44%
Camden Haven River	-0.75%	-3.59%	1.49%
Manning River	-0.72%	-3.47%	1.45%
Wallis Lake	-0.72%	-3.47%	1.45%
Port Stephens	-0.70%	-3.34%	1.39%
Hunter River	-0.76%	-3.64%	1.51%
Brisbane Water	-0.72%	-3.43%	1.43%
Hawkesbury River	-0.73%	-3.52%	1.47%
Shoalhaven River	-0.77%	-3.71%	1.55%
Crookhaven River	-0.75%	-3.62%	1.51%
Clyde River	-0.73%	-3.49%	1.45%
Tuross River	-0.76%	-3.62%	1.51%
Wagonga Inlet	-0.75%	-3.58%	1.49%
Wapengo Lagoon	-0.76%	-3.64%	1.52%
Merimbula Lake	-0.74%	-3.57%	1.49%
Pambula River	-0.73%	-3.50%	1.46%
Wonboyn River	-0.76%	-3.64%	1.52%

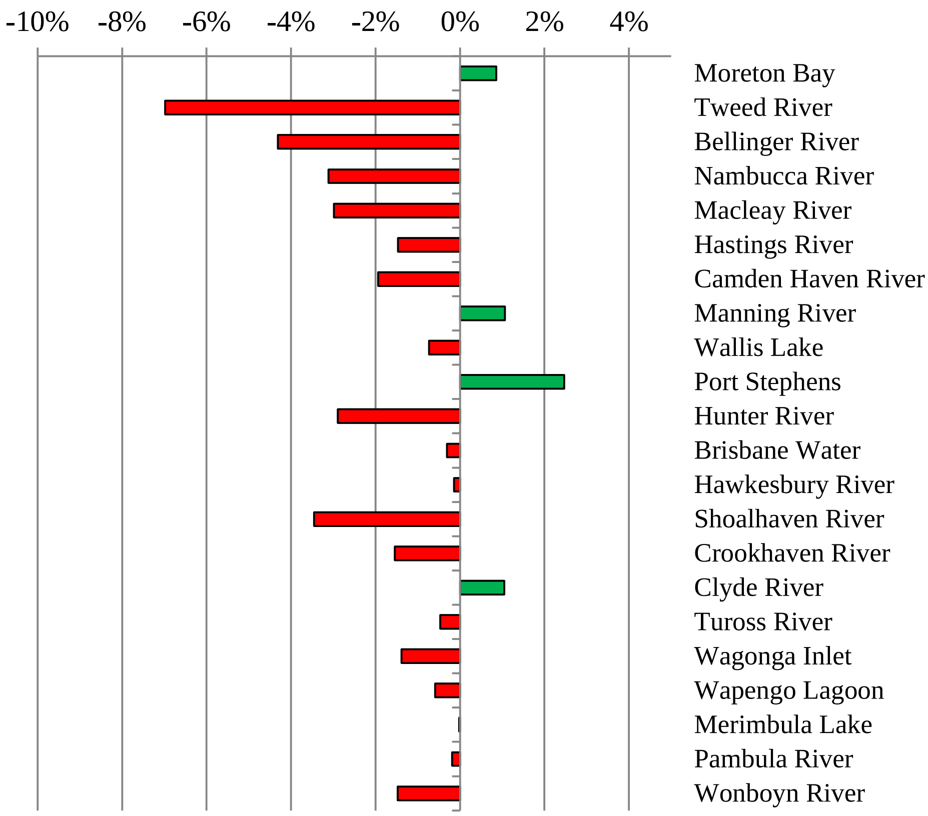
Note: PO for Pacific oyster; yellow indicates relative small or neutral change, red indicated relative large negative change, and green indicates relative large positive change in SRO revenue.

In the simulations we assumed that prices of SROs in all estuaries may be affected from changes in the supply of Pacific oysters by the same magnitude in all market scenarios. This explains the uniform outcome obtained for the impact of changes in the Pacific oyster supply on the revenue of SROs for each market scenario in Table 7.6.

The minor differences in the scale of change in revenue between the estuaries in each market scenario can be attributed to the differing production mix in each area which affects prices and, thus, the revenues of each estuary.

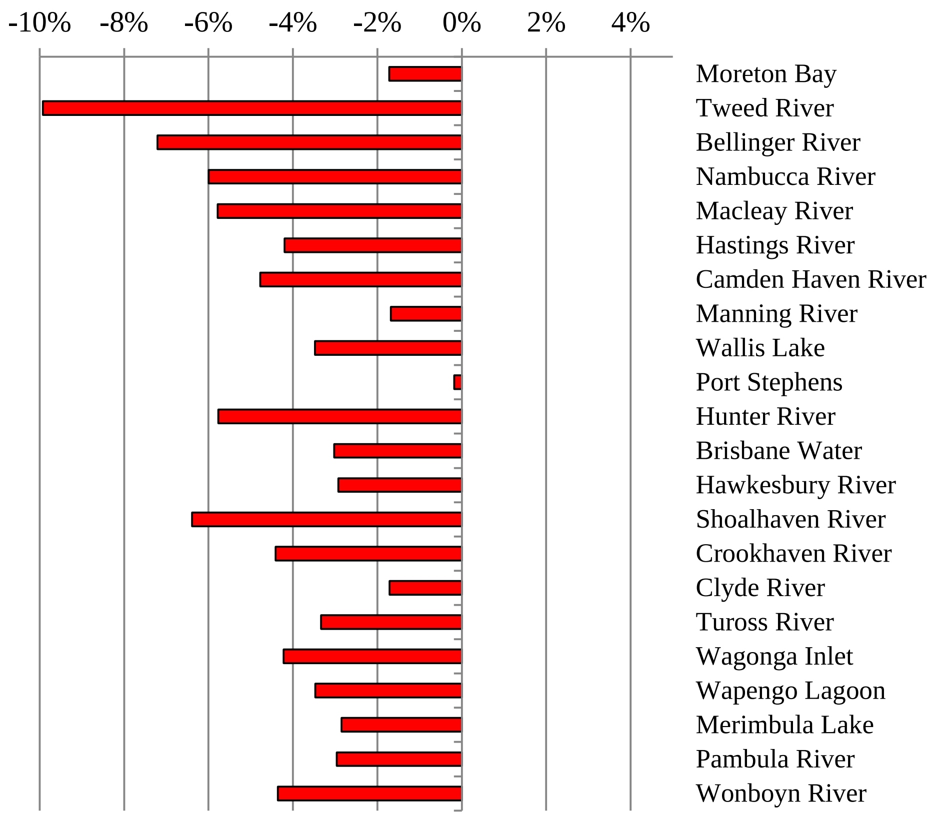
Due to the very similar results that we obtained for the three climate change scenarios (see Figure 7.5) we only applied the market scenarios to the LOW 50 climate scenario in order to derive estimations for combined climate and market scenarios. The results obtained for the combined LOW 50 climate and 5 per cent increase in Pacific oyster production market scenarios is shown in Figure 7.5.

Figure 7.5: Combined results for climate change and market scenario (Low 50, 5 per cent increase in Pacific oyster supply)



A comparison of the results in Figure 7.5 with results for the Low 50 climate outcome in Figure 7.4 shows that a 5 per cent increase in Pacific oyster production may diminish the revenue obtained under climate change settings in all estuaries (see also Table 7.6). This effect is likely to become more severe with an increase in Pacific oyster production to 24 per cent compared to observed production volumes (see Figure 7.6).

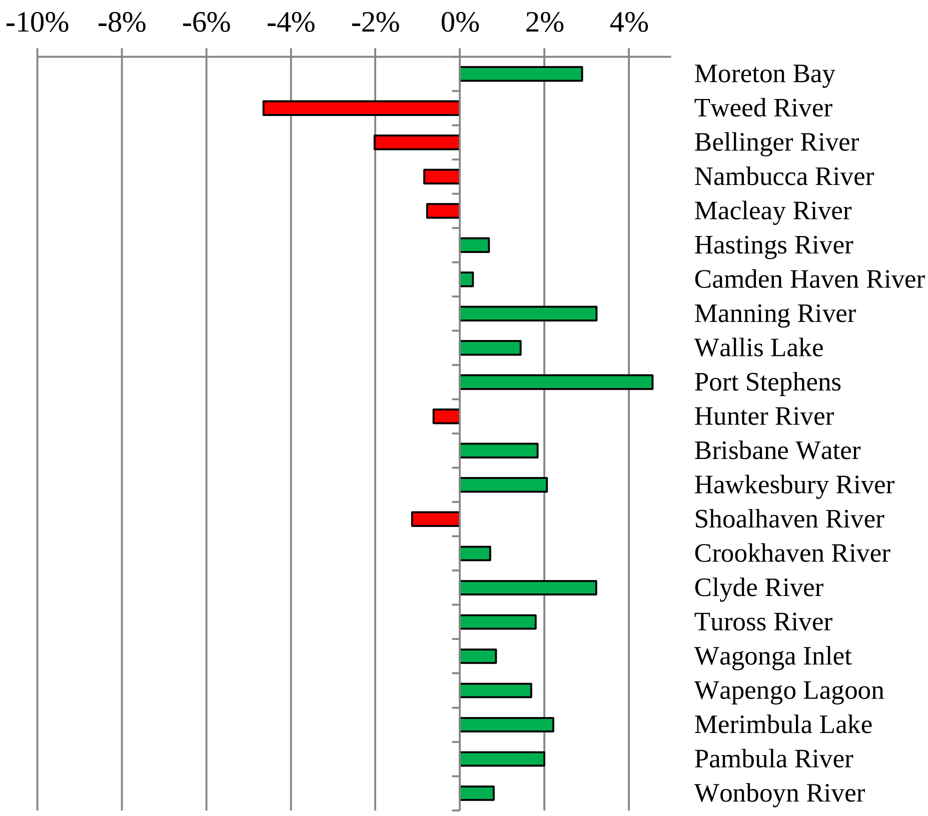
Figure 7.6: Combined results for climate change and market scenario (LOW 50, 24 per cent decrease in Pacific oyster supply)



The results in Figure 7.6 show that while climate change alone may provide some regions with advantages and other with disadvantages (see Figure 7.4), a significant expansion of the Pacific oyster production may reverse the economic advantages that selected estuaries may gain from climate change. A large increase in Pacific oyster supply is likely to exacerbate the economic viability of estuaries those revenues may be negatively affect from climate change.

Our results in Figure 7.7 suggest that a decrease in Pacific oyster supply would likely have a positive effect on SRO prices and, thus, could compensate for losses in revenue due to climate change.

Figure 7.7: Combined results for climate change and market scenario (LOW 50, 10 per cent decrease in Pacific oyster supply)



The combined results for the LOW 50 climate scenario and a 10 per cent decrease in Pacific oyster supply shows the importance of considering the role of market dynamics when assessing the impact of climate change on the economic viability of the SRO industry (see Figure 7.7).

7.5 DISCUSSION

The results of the revenue function estimation in Table 7.A (Appendix C) show that the own-price coefficients are significant, yet the cross-price coefficients are not significant except for the pair 'Bistro price and bottle price'. Based on this finding it could be assumed that these two products could be produced jointly which may lead to policy implications. However, this is not the case. The relationship between two price variables in this setting is an 'upward' substitution effect. This implies that if the price for bistro oysters goes up, fewer bottle oysters are produced. Yet, farmers can only harvest a single oyster either as bottle (small size) or as bistro (middle size). This decision can only be made at the stage when the oyster is of the smaller size. Therefore, the substitutability between oyster products in harvest decisions is only possible in an upward (size) direction.

Based on the results of the revenue function estimation in Table 7.A (Appendix C) we found that the revenue of the SRO industry has been relatively elastic to changes in temperature and salinity in the past (Table 7.4). We showed that the responsiveness of revenue due to changes in these biophysical variables in the past was influenced by the number of farmers and to lesser degree by the size of each estuary. This suggests that management aspects, represented by a large number of oyster farmers in an area, may have played a central role in how the industry was able to deal with the impact of biophysical change on oyster production processes. Local industry management may include, for example, collective decision making among oyster growers about appropriate stock handling in the presence of environmental pressure.

Our results also suggest that the industry's observed revenue was positively affected by output prices, which may not be surprising. However, our findings also indicate that the revenue was relatively inelastic to changes in output prices for any particular grade in the past, although the prices of the different grades are expected to move together, at least in the longer term. The presence of multicollinearity in the three price variables did not impair the power of the overall model but may affect the validity of the individual price variables. Yet, since we applied the cross-price elasticity between the two oyster species (which were derived in Chapter 5) to the bundle of SRO prices uniformly in the market scenario analysis of this study, a possible over-fitting of the model would not have exacerbate the results in the scenario analysis.

When comparing the effect of biophysical and price variables on the industry's revenue, the findings of this study suggest that biophysical variables may have a larger absolute effect on revenue than product price variables.

The results from the climate scenarios chosen in this study differ only to a minor degree. Based on our assumptions we found that the industry's future revenue may change by about +3.71 per cent to -6.22 per cent compared to the observed current revenue (see Table 7.5). This finding implies that the direct effect of climate change on the industry's economic sustainability may only be modest. For the interpretation of the results it should be considered that the period between 2012, the reference year of this study, and 2030, represents is a medium term planning horizon, which may explain the estimated modest economic quantification of direct climate change impacts on the industry.

Indirect factors, such as the occurrence of known or new diseases under changing climate conditions, may also influence future oyster production capacity. The economic implications of such events may have a significantly larger magnitude than the direct effect from climate change which we found in this study.

The findings from our analysis also indicated that the estimated future change in revenue may not occur uniformly across all production areas. While climate change may provide some production areas with a slight increase in revenue other may experience a decline. The spatial distribution of the estimated change to industry revenue under climate change appears to be less severe in southern NSW production region and Queensland, compared to northern NSW production areas. These spatial differences can be attributed to the assumption that revenue elasticities with respect to salinity and temperature, in each estuary may remain constant over time. The responsiveness of the revenue to changes in biophysical variables was predominantly influenced by the number of farmers and the size of production area in the past. Hence, the ability of the industry to deal with future environmental change will continue to depend on the capability of oyster farmers to respond to the potential challenges in SRO production. Initial adaptation strategies identified by the industry (Leith & Haward, 2010) should therefore continue to focus on investing in human capital, such as facilitation of cooperative actions, the provision of training opportunities, encouragement of communication and leadership.

The finding that all climate scenarios in our analysis return very similar results can be explained by the relatively small change in absolute values predicted for salinity and temperature across the emission scenarios (see CSIRO and Bureau of Meteorology (2007)). For example, the average observed temperature in Moreton Bay was 22.48 °C (Healthy Waterways Ltd, 2012). An increase by 0.48 °C (LOW 50) and 0.60 °C (HIGH 90) may mean that the new average temperature may still be within the temperature range considered as optimal of all life stages of oysters (see Table 7.1).

Furthermore, in our study we use average observed values for temperature and salinity as well as average change projections for these variables. The use of extreme observed data for salinity and temperature (*e.g.*, minima and maxima) as well as their frequency and duration may have provided more severe estimation outcomes for the industries' future revenue. Yet, such data was unavailable.

The results for market dynamics simulation shows that the higher the future supply of Pacific oysters the worse affected will be the future revenue of the SRO industry. This finding is based on the previously established relationship between both commercial oyster species, which we assumed remain constant under future scenarios. In our study we assumed that the change in Pacific oyster production volume affects oyster prices uniformly across all production regions, which explains why all estuaries' revenue may be affected in similar magnitude by the assumed market dynamics.

Our results for the combined climate and market scenarios show that market dynamics can exacerbate, smooth or reverse the negative economic impact from climate change on the industry. These findings also suggest that the likely future economic viability of the SRO industry will much depend on the development in Australia's Pacific oyster industry should current market settings continue in future. The management of the SRO industry should therefore carefully assess policies that may affect the market relationship among these two oyster species. Furthermore, we argue that the market relationship among commercial oyster species should not be ignored in any future industry development strategy of the industry. In this study we only considered one angle of market dynamics, other market aspects that may affect the future economic viability for the SRO industry may include, for example, advanced marketing strategies that may affect the demand for this oyster species, improvements along its supply chain (Hobday *et al.*, 2013; Plagányi *et al.*, 2014) in order to improve the bargaining power of oyster growers for higher farm gate prices, as well as broader seafood market dynamics.

A review of the scientific literature that focuses on how climate change may influence the productive capacity of the SRO industry showed that there has been limited research effort to date in this field. The scientific literature clearly shows that the research about the SRO currently concentrates on dealing with present environmental challenges, such as QX disease (*e.g.*, Dove *et al.* (2012), Green *et al.*

(2011), Green and Barns (2010b), Simonian *et al.* (2009), and Butt and Raftos (2008)) and the development of selectively bred stock is resistant to this diseases (*e.g.*, Dove and O'Connor (2012), Hand *et al.* (2004), Nell and Hand (2003)). An increased focus on identifying potential climate change related risks to SRO production could provide industry managers and oyster growers more certainty to about how to assess and manage these potential risks appropriately.

Major limitations of this study may include the use of proxy data used in the absence of projections of changes in salinity and temperature in estuaries. Furthermore, constant treatment of production inputs, costs, SRO own-price elasticity, other environmental variables, regulatory framework and the dynamics in the Australian seafood market are significant and might bias the findings of this study.

7.6 CONCLUSION

The aim of this study was to assess the potential impact climate change, estimated for the year 2030, and market dynamics on the future economic viability of the SRO industry.

The findings from this study reveal that the effect of projected climate change on the industry's revenue is likely to be only moderate overall should the industry carry on with business as usual. However, some oyster production areas may likely be more affected than others. Yet, indirect effects from climate change on oyster production capacity, *e.g.*, the occurrence of diseases, may have more severe implications for the industry's future economic viability than the direct consequences from climate change which we investigated in this study.

Our results suggest that the handling of local environmental challenges has played a major role in the economic viability of the industry in the past. Local and industry wide management strategies which deal with the potential challenges that climate change may present in future will play a significant role in the industry's ability to maintain its economic viability. Adaptation strategies should therefore not only focus on enhancing selective breeding efforts to obtain resilient oysters or foster innovative production technologies but also focus on facilitating human capital investment (*e.g.*, provide training opportunities, support collective action, encourage communication, leadership and participation in decision making processes).

Furthermore, the findings from this work suggest that market dynamics could have a larger impact on the economic sustainability than direct effects from climate change, should the market relationship between Australia's key commercial oyster species continue in future. Consequently, the industry management should consider market settings in any climate change adaptation planning as well as general development strategies of the industry.

The findings of this study can be considered as baseline against which already identified management adaptation strategies can be compared and identifies production areas where changes in management may be necessary to capture the potential benefits or mitigate the potential losses from climate change.

The following Chapter 8 will summarise the findings from the studies in Chapter 4-7 and implications of the findings for industry management and policy will be discussed.

Chapter 8: Discussion and conclusion

8.1 INTRODUCTION

The Sydney rock oyster industry – one of the oldest industries in Australia – has declined substantially in production over the last few decades and even more so over the last century. While disease has been a contributor to this decline, in some areas in particular, there is evidence that economic factors have also contributed to the decline in production.

The industry holds a unique position in Australian aquaculture as it is the only industry based on a species purely endemic to the east coast of Australia. To this end, the industry is playing a role in conserving this species as well as utilising it. Without commercial farming, and its associated management, overfishing from recreational oyster gatherers would have likely depleted the stocks to low levels, as has been the case of other native oyster species (O'Connor & Dove, 2009).

Decreases in production may have resulted for three reasons. First, declining prices may have made production less viable and resulted in a contraction in the industry. Second, changes in productivity may have occurred through changes in producer efficiency. Third, environmental factors may also have reduced productivity. Identifying the relative impact of these drivers on productivity is essential if the industry management is to develop an appropriate policy response to achieve its objective of increased production.

The research undertaken in this thesis was aimed at determining the impact of these drivers on oyster production, with the aim of providing appropriate policy advice to managers and industry. In the following sections, we summarise the work conducted in this thesis. We also discuss the implications of the findings generated in this thesis for management and policy. Contributions to knowledge, areas for future research and limitations of this dissertation are also outlined.

8.2 HYPOTHESIS, OBJECTIVE AND RESEARCH AIMS

In this thesis we hypothesised that the decline in productive volume of the SRO industry is not only a result of environmental issues but potentially also caused by economics aspects that relate to the industry. In order to verify this hypothesis, the objective of this thesis was to enhance the understanding of the economic status quo and potential future economic viability of the SRO industry. This led to research questions:

- What is the current socio-economic profile of the industry? What is its role in the industry's economic performance?
- How does change in production affect oyster prices? And how has increased Pacific oyster production affected the prices of SROs?
- What is the level of production efficiency in the industry? What are the main drivers of efficiency in the industry: Producer characteristics or external factors (*e.g.*, environmental factors)?
- How is climate change likely to affect the industry in the medium term? Who may be the winners and who may be the losers?
- What are the key focal areas that policy and management should consider in order to support a sustainable future development of the SRO industry?

Knowledge about these economic aspects is essential to understand the drivers of the industry's performance as well as its future sustainability. Should these economic dimensions of oyster farming not be understood or considered, policy interventions and industry management could result in governance failure, unintended externalities, social issues in coastal communities and ecological tragedies of common goods. Furthermore, the potential loss of this traditional industry would also mean a loss of considerable existing cultural and heritage value to the Australian society.

8.3 KEY RESULTS

In order to address the hypothesis four studies that correspond with aim 1 to 4 of this thesis were undertaken. Each of these studies has created valuable information about the SRO industry that can support its future management and policy decision making. The most important findings are summarised as follows.

8.3.1 Socio-economic industry profile

Aim 1 of this dissertation was to develop a socio-economic profile of the key stakeholders of the SRO industry. Information about demographic characteristics of oyster farmers is important as it provides details on why the industry is structured and performing like it is. It may also provide insights into how the industry may develop in the future.

The key findings from the socio-economic profile of the SRO industry in Chapter 4 suggested that the oyster industry in NSW and Queensland is dealing with an aging oyster grower population. The results of this study also showed that a large proportion of oyster farmers entered the industry in pre-retirement age and that a relatively low proportion of oyster grower's household income comes from oyster farming. This suggested that SRO farming is mostly undertaken as part-time activity. Our results endorsed previous industry production statistics that showed that SRO farming is mostly conducted on a small-scale business level.

The presence of a relatively low number of young oyster farmers in this industry raised the question about potential industry entry barriers which has previously not been investigated. Given the current age structure of the SRO industry members their ability to drive/support innovation and their translations into industry practise as well as willingness to co-operate with research institutions may be compromised and, hence, hamper future industry development.

The results from the survey analysis also revealed that the SRO oyster farmers have a relatively pessimistic opinion about the future of the industry which is driven by challenges within the oyster production process and subsequent profitability concerns. Furthermore, we provided evidence that the industry members are much divided about the introduction of Pacific oyster varieties in NSW and Queensland. Based on the developed socio-economic profile for the SRO industry we concluded that the future development of the industry will also depend on the ability of the industry management to address the socio-economic issues present in this industry.

The demographic characteristics of farmers may also affect producer efficiency of the industry, thus the data collected in this study was also used for a subsequent component of the dissertation.

8.3.2 Market relationship between SRO and Pacific oyster

The decline in the SRO industry has also been accompanied by a substantial increase in the production of Pacific oysters, particularly in South Australia. SRO prices have correspondingly declined. One potential explanation for this is that the oysters compete in the same market, and hence the Pacific oyster expansion may have had a detrimental impact on SRO price, and hence production.

The aim of the study presented in Chapter 5 was to investigate whether the markets for the two main commercial edible oyster species, the SRO and the Pacific oyster, in Australia are integrated and thus if the two species are considered the same products. Furthermore, we examined the short- and long-run own- and cross-price flexibilities of the two commercial oyster species in order to identify any price-quality dynamics.

The results of the cointegration analysis showed that the price of the largest oyster producing States for each species, NSW and South Australia hold a long-run relationship in which NSW appeared to be the price leader. Yet, the oysters in NSW and South Australia were not found to be perfect substitutes, which lead to the conclusion that markets in the major oyster producing State for each species are not fully integrated.

The estimation of SRO own-price flexibility suggested that the price adjustments, resulting from changes in quantities supplied within the SRO market segment, are more responsive in the long-run than in the short-run. This means that changes in SRO supply have little effect on the price of SROs immediately, but may do so over time. Conversely, the own-price flexibility for Pacific oysters indicated that changes in the supply of Pacific oysters have a large effect on the price of Pacific oysters. This effect was more prominent in the short-run than in the long-run. This suggests that Pacific oysters face a relatively elastic demand. We also found that changes in the quantities supplied of Pacific oysters had a significant negative impact on the price formation of SROs but not vice versa. This may explain why the demand for oysters in our study shifted towards the cheaper and higher volume Pacific oyster, which decreased demand for SROs.

8.3.3 Productive efficiency and capacity utilisation analysis

Aim 3 of this thesis was to assess productivity measures and to determine the drivers of productivity within the SRO industry. The analysis focused on a case study relating to Moreton Bay, the northern most SRO cultivation area. We assessed productivity measures such as technical efficiency, scale efficiency, allocative efficiency and capacity utilisation (see Chapter 6). In a second stage of the analysis we examined the influence of demographic characteristics and environmental conditions at oyster leases on observed productivity levels. We also investigated the extent to which these exogenous production factors could be influenced by management to enhance productivity of the industry.

We found that there is a relatively low level of technical efficiency in the Moreton Bay oyster industry on average, although some producers are highly efficient. Some of this can be explained by differences in environmental conditions in Moreton Bay. We concluded that improvements in water quality in the Bay may result in increased productivity in the industry. However, some demographic traits of the oyster farmers were also found significant drivers of efficiency. In particular, the high number of pre-retirement hobbyists present in this industry who potentially undertake their oyster business with a low incentive for technical efficiency, and also potentially with the wrong skill set to operate efficiently. We concluded that forcing these producers out of the industry through command and control measures may not be effective in increasing productivity as there are few incentives for younger farmers to enter the industry. Hence, the development of appropriate training programs aimed at specific skills may be a more effective means of improving efficiency in the industry.

8.3.4 Climate change

The aim for the study presented in Chapter 7 was to establish the simulated impact of environmental change and potential increases in Pacific oyster production on the future economic viability of the SRO industry. Based on our assumptions the findings from this study suggested that the negative effect of projected climate change on the industry's revenue is likely only to be moderate should the industry carry on with business-as-usual. Yet, some oyster production areas may likely be more affected than others. The southern most producing areas may potentially benefit from changing climate, while most northern areas are likely to be adversely affected. Surprising, Moreton Bay – the northern most region – is likely to also benefit as a result of the structure of the industry in the Bay which enables greater resilience to climate change.

We found that the handling of local environmental challenges has played a major role in maintaining the economic viability of the industry in the past and we concluded that local ability to deal with environmental issues may become the key factor in maintaining the industries' economic sustainability.

We concluded further that adaptation strategies to climate change should not only foster innovative production technologies but also focus on facilitating human capital investment (*e.g.*, provision of training opportunities, support of collective action, and encouragement of communication among farmers and leadership and participation in decision making processes).

The study also revealed that market dynamics could have a larger impact on the economic sustainability than direct effects from climate change. Consequently, market settings in climate change adaptation planning should be considered in the industry's development strategies.

8.3.5 Validation of hypothesis

The combined findings from the four studies undertaken under the research framework of this dissertation confirmed that economic aspects have likely affected the economic performance of the SRO industry in the past and may likely do so in the future. However, we have also provided evidence that environmental conditions, such as water quality and climate change, have affected oyster production in the past. These findings suggested that the hypothesis of this thesis can be validated. This implies that environmental as well as economic aspects of the SRO industry are important to be considered in industry management and policy making in order to avoid management and government failure, economic loss, and the environmental tragedy of the commons.

8.4 CONTRIBUTIONS TO KNOWLEDGE

This dissertation provided the first set of economic analyses to assess the economic status quo of the SRO industry. Thus, the results generated from the research are novel and enhance the economic understanding about the SRO industry.

The analysis tools employed and the integrated economic analysis structure presented in this thesis provide an example that can also be applied to other aquaculture industries.

To our knowledge this thesis produced the first socio-economic profile of an Australian aquaculture industry. We showed that the demographic characteristics of oyster farmers partly explain why the industry is structured and performing like it is. We also provided some insights about how the industry may develop in future if these structural issues remain unattended. The profile and methodology used to generate this summary about oyster farmers may be of interest to other industries that are dealing with similar issues like the SRO industry.

A further contribution to the knowledge about this industry was made by developing the first model of price formation for Australia's commercial edible oyster industry. In this thesis we have also established the first demand model for the Australian oyster market and we were able to verify that increased Pacific oyster supply did have a negative impact on prices for SRO. This is valuable information, which can be used to inform decision makers about the likely economic impact of an expansion of the Pacific oyster industry in NSW on the SRO industry. The study about price formation and demand analysis of the Australian edible oyster industry also contributed to scholarly knowledge as peer-reviewed publication to the literature in the field of aquaculture economics and management.

Furthermore, by using data envelopment analysis and a second stage analysis we provided evidence in a case study that demographic and environmental conditions affect the productive efficiency of the industry. These findings suggested that water quality improvements and appropriate training can potentially provide the greatest benefit to the industry. While these results are not directly transferable to other industries, the methods are, and provide means by which coastal aquaculture may be managed to ensure it remains competitive with other uses of coastal resources, such as tourism.

A contribution to scholarly knowledge was made by developing of a bio-economic model, in form of an adapted revenue function. This model allows the simulation of the potential impacts of climate change and market dynamics on the future economic viability of an industry. To our knowledge, this is the first model that allows a quantification of the potential impact of climate change on the economic viability of an aquaculture industry. Furthermore, the role of markets in climate change scenario analyses has found very limited consideration in the literature to date. In this dissertation, we showed that the market dynamics for seafood products is important to be considered in adaptation strategies since these dynamics can potentially offset positive economic effects from climate change and could exacerbate negative economic effects. This is an important contribution to the literature in the field of climate change adaptation research.

Most importantly, this dissertation offered a broader picture of the current economic performance of the industry and enables an assessment of its short- and medium-term economic viability. The studies presented in this thesis provide the foundation for the development of key focal areas for policy and management consideration that may support a sustainable future of the SRO industry. These key areas will be outlined and discussed in the following section.

8.5 MANAGEMENT AND POLICY IMPLICATIONS

The environmental and economic viability of the SRO industry is of significance for coastal communities as this industry provides them employment and income opportunities. However, economic aspects that concern the SRO industry have largely not been considered in past industry development strategies. Based on the key results of this dissertation a review of current policies and industry development strategies was undertaken to address the following research question: What are the key focal areas that policy and management should consider in order to support a sustainable future development of the SRO industry? The response to this question translates to aim 5 of this thesis. The key recommendations will be outlined and discussed as follows.

8.5.1 Human capital investment

Human capital relates to the set of competencies and knowledge that result in the ability of individuals to produce economic value (Hubbard *et al.*, 2010). Hence, a high quality of human capital is an important input factor for production processes and economic growth.

In this dissertation we have shown that the socio-economic characteristics of farmers in the SRO industry have affected the level of efficiency with which oyster farming is undertaken. Given the relatively mature age at which the majority of oyster farmers enter the industry and the relatively high educational level of educational that oyster farmers attained, we concluded that a number of farmers potentially have the wrong skills for oyster farming (Chapter 6). Oyster farming is a much specialised activity which requires knowledge and skills in a range of fields such as oyster biology and growth factor, farming techniques, farm management, and marketing.

Furthermore, the ability of oyster farmers to cooperate with other oyster farmers, particularly on an estuary and regional level, is important in order to deal with production risks such as diseases and water quality issues appropriately (Chapter 7). Moreover, the capacity of farmers to adapt to climate change is important to ensure the future economic sustainability of oyster farming. This is supported by recent findings from Lim-Camacho *et al*. (2014), who illustrated the fundamental role of agility and capability (which also includes taking advantage of arising opportunities) of fishers and aquacultualists in their perceived climate change adaption processes.

Based in these observations, the current use-it-or-lose-it policies (minimum product levels) in Queensland are unlikely to attract new entrants and provide the wrong incentives to the existing producers who don't have the right skill set.

Given the central role of oyster farmers in the future development of the SRO industry we suggest that industry management should focus on investing in improving labour skills. This may include the attraction of young, innovative and enthusiastic people to the industry and the development of appropriate training programs aimed at specific skills required in oyster farming.

Attracting young, innovative and enthusiastic people to the industry will be a challenge for this industry as opportunity cost for young people may be high and entry barriers to the industry may exist. However, in order to find out details about the factors that may attract young people to join the industry a survey of farmers who have entered the industry in recent years could be undertaken. The survey could focus on potential opportunity costs (*e.g.*, what are alternative employment options in relatively remote coastal areas), perceived and actual industry entry barriers (*e.g.*, access to capital, skill development), and motivational factors (*e.g.*, working outside, being their own boss). Findings from such a survey could provide the foundation to develop a strategy to promote the industry to potential new members and assist new industry members in the establishment of their oyster farm business.

The development of appropriate training programs aimed at the improvement of specific skills should be driven by demand. Surveys of required skills could help guiding the development of appropriate training programs.

8.5.2 Fostering oyster farmer participation in industry matters

In Chapter 4 we found that the proportion of oyster farmers who are members in producer organisations is relatively high and we concluded that cooperation with the industry is likely also high (Chapter 7). While this may be the case, there appears to be a lack of participation or contribution of farmers in the strategic development of the industry and in other industry related matters (Leith & Haward, 2010). The lack of participative management in the SRO industry is likely a result of its demographic profile and individual oyster farming approaches. The present lack of industry member's participation in industry matters is an concern as it may affect the effectiveness of future industry management strategies (see section 8.5.8) and may also be a social barrier to climate change adaptation (see section 8.5.6). Evidence from other organisational settings exists which show that internal governance is most effective when the rules and guidelines emerge from within the user group rather than being imposed by a distant authority (Ostrom, 1990). An enhanced understanding about how decisions are made is the key to openness, trust and ultimately to acceptance of the management structures (Gallagher *et al.*, 2004).

In order to enhance the participative management within the SRO industry we suggest the industry management to increase its liaison with oyster producer organisations and to provide oyster growers opportunities to engage with each other and other key industry stakeholders. Since a participative management approach potentially bears opportunity costs for farmers (*e.g.*, time, travel costs), incentive based participation should be considered. An example for incentive based participative management could be an annual industry meeting which provides the opportunity to communicate, network, exchange experiences and news but could also offer workshops, presentations from researchers and discussion forums. This may also be considered to be undertaken in a similar format on a regional scale on a more regular basis.

8.5.3 Lobbing for improved water quality in estuaries

In a case study for Moreton Bay we verified that some of the observed low productivity in the industry can be explained by environmental conditions in this estuary (Chapter 6). We concluded that an improvement in water quality will likely affect the productivity in this estuary positively.

Water quality in estuaries is an external production factor for oyster production that cannot be directly influenced by management of oyster growers. However, a high level of water quality in estuaries is not only of benefit to the oyster industry but also to tourism industries (*e.g.,* scuba diving), conservation (*e.g.,* marine parks) and recreation (*e.g.,* fishing).

Working collaboratively with all stakeholders who use the coastal waterways or have an interest in the water quality of these coastal ecosystems (*e.g.,* government, councils, industry and community) is essential to protect and improve the health of estuaries on Australia's east coast. An example for a successful not-for-profit, non-government initiative of stakeholders that have an interest in are high coastal water quality is the Healthy Waterways Partnership in south-east Queensland (Abal *et al.*, 2006).

We suggest the oyster industry in Moreton Bay and other estuaries to engage in such initiatives by publicly expressing their interest in water quality improvements and possibly by lobbying for stricter enforcement of penalties and monitoring of water pollution (*e.g.,* sewage overflow, boat traffic) or non-point source pollution from upper catchment activities (*e.g.,* agricultural activities).

While this may not provide short-term solutions to present water quality issues in oyster producing estuaries along the NSW and Queensland coasts, it will likely be beneficial for the industry in the medium-term if farmers are less affected by externalities from coastal development.

8.5.4 Consideration of cost and benefits of oyster aquaculture diversification

Diversifying oyster aquaculture production by expanding the cultivation of other oyster species may be an option to keep the oyster industry economically viable in future. While in Queensland all Pacific oyster production remains prohibited, the NSW OISAS states that a diversification of the oyster aquaculture industry will focus on expanding triploid Pacific oyster and the native flat oyster production (NSW DPI, 2014b).

Our farm survey results in Chapter 4 revealed that SRO growers are much divided about the introduction of Pacific oyster varieties, which reflects the difficulty of the industry management and regulators to respond to economic losses in the SRO industry by employing alternative industry management strategies.

However, there is a range of benefits associated with expanding the production of other oyster species in NSW. These benefits may include an:

> *"[...] increase [in] returns to industry, [an] improve[ment in] business resilience and [...] a more productive use of an oyster aquaculture lease area."* (NSW DPI, 2014b)

The expansion of triploid Pacific oyster and native flat oyster production appears to be commercially attractive due to their faster growth compared to the SRO (Hurwood *et al.*, 2005). While the triploid Pacific oyster is already grown in five estuaries and is on trial in two further estuaries (NSW DPI, 2014b), the native flat oyster is currently only cultivated in small quantities in selected estuaries (NSW DPI, 2014a).

Yet, an increasing expansion of production into other oyster species, particularly into triploid Pacific oyster production, may be associated with significant costs.

For example, our results in Chapter 5 provided evidence that changes in the quantities supplied of Pacific oysters (from Tasmania and South Australia) had a significant negative impact on the price formation of SROs in the past but not vice versa. We concluded that the expansion of the Pacific oyster industry affected the profitability of the SRO industry negatively. Assuming that consumers remain unable to differentiate between diploid and triploid Pacific oysters, a further expansion of triploid Pacific oyster cultivation in NSW may have a positive effect on the revenue of farmers who choose to diversify their oyster production. Yet, at the same time the pressure on the economic viability of the remaining SRO growers may increase due to an increasing supply of triploid Pacific oysters in NSW. This is a trade-off that may have not been considered by policy makers and industry managers in the past and which may lead to unintended welfare distribution outcomes from oyster framing in coastal communities in NSW. Consequently, an additional expansion of the triploid Pacific oyster production in NSW may lead to a further contraction of the SRO industry in future. Thus, market interactions between SROs and triploid Pacific oysters should not be ignored in the future when setting effective policies and industry management strategies.

The expansion of the triploid Pacific oyster industry in NSW may also lead to increasing biosecurity monitoring costs. Triploid Pacific oysters have a greatly reduced reproductive potential compared to diploid Pacific oysters and are therefore selected for aquaculture and considered as non-invasive (Gong *et al.*, 2004). Yet, there is evidence that triploid Pacific oysters are not completely sterile and cannot provide complete containment (Gong *et al.*, 2004). This biosecurity risk will need to be continuously monitored by the regulative agency and thus monitoring costs are likely to increase with increasing production of triploid Pacific oysters.

Further concerns provide the present structural issues which relate to the demographic profile of the SRO industry and which will not be eliminated by employing alternative oyster production strategies. The introduction of commercially more attractive oyster species may provide current oyster farmers an option to maintain their economic viability in the short-run. Yet, without structural reforms (*e.g.,* human capital investment, fostering innovation) of the industry it is unlikely that the diversification of oyster aquaculture in NSW will contribute to an environmentally and economically sustainable oyster aquaculture industry in NSW in the medium- or long-run.

Furthermore, it should be noted that other oyster species are not immune to diseases (*e.g.,* the triploid Pacific oysters industry was affected by a POMS outbreak in 2010/11 (NSW DPI, 2014c)) and production output of these oyster species may also be affected negatively by severe disease outbreaks.

Although there is a range of potential benefits from diversifying oyster aquaculture production, the likely costs and concerns about the role of farmer’s demographics in the future development of the industry need to be considered in the decision making process about the expansion of the industry into cultivating other oyster species.

8.5.5 Investigation of the social value of the SRO as a native oyster species

The SRO is a unique oyster species that is only endemic to Australia's east coast. At this stage, the SRO is not an endangered species and the physical replacement of the SROs with triploid Pacific oysters in selected NSW estuaries may not present an immediate risk for the displacement of the native species. While the industry is currently keeping the natural stock of SRO high by cultivating this native species, the question arises how resilient the stock would become if SRO cultivation would be increasingly replaced by triploid Pacific oysters.

The 'value' of the SRO industry largely derives from its economic contribution, particularly to rural communities in NSW. In addition, this industry has a cultural and heritage value to the Australian society due to its vital position in the historic development of Australian aquaculture. The SRO may also have a social value which may be derived from a collective benefit of keeping estuarine ecosystem in relative balance at potential economic costs for SRO oyster farmers, *e.g.*, by limiting farms to become increasing productive using a commercially more attractive non-native species. This potential social value of the native oyster species has not yet been investigated but should be considered for further oyster industry development planning, particularly if the policy makers consider expanding areas allocated to triploid Pacific oyster production. Investigating the social value of a native oyster species could be conducted in a non-market valuation analysis but also by using tools provided in the field of behavioural economics that allow, for example, an assessment of individual's attitudes and preferences towards the use of renewable natural resources.

In the absence of findings from such an analysis, environmental monitoring and compliance with production guidelines should continue to be rigorously conducted and enforced to ensure that triploid Pacific oyster production does not become a risk to estuarine ecosystems, including the native SROs.

8.5.6 Adaption to climate change

The effects of climate change in Australia have already been observed and reported in a range of studies (CSIRO & Bureau of Meteorology, 2007; Hobday *et* *al.*, 2008; Lough & Hobday, 2011; Poloczanska *et al.*, 2007). However, climate change may not yet be perceived as an immediate risk to industries that relay on natural renewable resources since producers may have not yet been affected by significant and continuous changes to production conditions.

Yet, early adaptation to climate change is important for natural resource based industries in order to avoid a later loss in production capacity, industry profitability and welfare for coastal communities. Early or anticipatory adaptation planning to climate change includes the development of an understanding of the potential risks from climate change to the productive capacity of an industry. Based on such knowledge management options to mitigate such risks can be developed, which can take technological, economic, managerial and institutional forms (B. Smith *et al.*, 2000).

Climate change is a concern to the SRO industry and as such is acknowledged as a risk to oyster production in the NSW industry development strategy (NSW DPI, 2014b). It is addressed as follows:

> *"The best way to deal with this uncertainty [about timing and impact of climate change] is to maximise the industry's ability to adapt to the changes when they occur."* (NSW DPI, 2014b)

However, the industry development plan for the Queensland oyster industry neither mentions climate change nor addresses climate change adaptation strategies (QLD DPI&F, 2008a).

The findings from the study in Chapter 7 suggest that the direct impact of climate change, such as changes in water temperature and salinity will likely affect the economic viability of the SRO industry only moderately on average, but some areas will be winners and others losers. Yet, these results were derived under the assumption that all other production conditions remain constant. The true economic impact of climate change on the SRO industry may likely be more severe than we found in Chapter 7, *e.g.*, by potentially more frequently occurring diseases triggered by environmental change. This highlights the need for climate change adaptation planning.

The SRO industry in NSW has already undertaken first efforts in mapping out potential environmental factors (*e.g.*, changes in temperature, pH, salinity) that may affect the productive capacity of the industry under increasing climate change conditions (Leith & Haward, 2010). Yet, only a limited range of scientific studies has so far investigated the possible impact of these factors on oyster health and development (see Chapter 7.1). In order to broaden the understanding how climate change or climate related changes to estuarine ecosystems may affect health and growth of oyster populations, and thus the natural productive capacity the industry, we suggest continuing and increasing scientific research efforts in this area.

The management of the identified risks for the industry from climate change include the development of adaptation strategies, such as maximising the ability of an industry to respond to changes (NSW DPI, 2014b). Leith and Haward (2010) highlighted the need for investment in human, social, physical and financial capital in order to improve the adaptive capacity of the SRO industry.

Economic constraints to the adaptive capacity may particularly exist for low-income farmers who may not be able to afford equipment, gear replacement or operation of new engineering structures (Mahon, 2002). Budget constraints can pose a barriers to adaptation, particularly if high upfront costs are involved (Monirul Islam *et al.*, 2014). Those oyster farmers with limited financial capital and access to it will either leave the industry or will focus on short-term gain rather than on the potential long-term benefits of reduced vulnerability from investments (Monirul Islam *et al.*, 2014). There is also a potential social barrier to climate change adaptation present in the SRO industry. This may include farmers limited knowledge about climate change and its potential impact on the productive capacity of SROs as well as their risk perception and interpretation of climate change (Monirul Islam *et al.*, 2014). Formal institutional barriers may constrain the adaption process because they define the processes and rules; prioritise the industry wide actions and adaptation development strategies.

Although the current NSW industry development strategy (NSW DPI, 2014b) lists some areas for adaptation to climate change (*e.g.*, improvement of communication and cooperation among industry stakeholders; the development of environmental monitoring programs to understand current conditions and to detect change), a planned approach for climate change adaptation of the SRO industry is currently unavailable which may pose an institutional adaptation barrier.

Therefore, we recommend a more strategic and concerted effort towards a better understanding of how climate change will affect the productive capacity of the industry and the development of strategies that minimise current barriers to the adaptive capacity of the industry to climate change. We suggest developing a clear catalogue of climate change related research areas in the field of bio-scientific research and socio-economic research (*e.g.*, human resource development, perception of climate change and its impact on farm decision making). This catalogue should be developed in a participatory manner between industry management, oyster farmers and research institutions as well as other Government institutions.

8.5.7 Continuous close liaison with research institution and fostering innovation

The SRO industry is already facilitating and supporting research in the area of biological and ecological science with the aim to promote the oyster production. Based on the research that was conducted in this thesis, and particularly the finding that there may be a lack in specialised labour skill present in this industry, we conclude that the industry will remain dependent on a continuous close liaison with research institutions in order to create knowledge and to foster innovation.

Given the evidence that we provided in this thesis that socio-economic dimensions of oyster farming likely affect the economic viability of this industry we also recommend broadening research efforts from a biological/ecological focus to socio-economic and business fields.

However, this will demand an increased level of research coordination, which may include the:

a) identification of key focus areas in the fields of scientific, socio-economic, and business research,

b) liaison with research institutions on the potential development of research projects, *e.g.*, Honours, Master or PhD project, with an applied research focus that benefit the SRO industry,

c) encouragement of an participatory research approach between research institution, oyster farmers and industry management,

d) consideration of research co-funding from the SRO industry (*e.g.,* top-up scholarship) to support the engagement of research institutions should be considered, and

e) opportunities for researchers to disseminate their findings (*e.g.*, at annual meetings or workshops).

The management of the NSW SRO industry has already adopted some of these research coordination tasks but should consider expanding these to the list provided above.

In terms of prioritising research areas we suggest to continue current efforts in the areas of disease prevention and resistance. Understanding how climate change may affect oyster health and development should become another focus area in the field of biological/ecological research (see section 8.5.6). A research area in the socio-economic field that should be considered to be undertaken in cooperation with a research institution is the investigation of opportunity costs, potential perceived and actual industry entry barrier and motives for industry entry (see section 8.5.1). Furthermore, a comparative study based on the framework of this dissertation with the Pacific oyster industry should also be considered. The results of such a study could reveal social, economic but also managerial differences between the industries which may provide the management of both industries ideas for improvement. In the field of business research the question 'How to enhance the price bargaining power of oyster growers?' could be investigated. To answer this question, a range of studies could be conducted which may include a further exploration of consumer demand for oysters and industry specific marketing strategies (*e.g.*, combination of tourism, fine food and oyster farming experience). In order to overcome oyster farmer's lack of market information, the development of an online market information tool (*e.g.*, partially operated by oyster growers) could also be undertaken.

8.5.8 Review of industry development strategies

The current industry development strategies, which are the NSW OISAS (NSW DPI, 2014b) and the Oyster Industry Management Plan for the Moreton Bay Marine Park (QLD DPI&F, 2008a), focus almost exclusively on production guidelines and the environmental sustainability of the SRO industry. The findings of this dissertation verified that not only environmental aspects but also economic dimensions of oyster farming need to be considered to ensure the long-term viability of the SRO industry. Based on the outcome of the previous four studies we recommend a review of both oyster industry strategies and suggest the consideration of:

a) the development of realistic production goals that consider environmental, social (*e.g.* industry demographics, business approaches in oyster framing) and economic (*e.g.*, seafood markets, productivity levels) information about the oyster industry (see sections 8.5.1, 8.5.2, 8.5.3),

b) a possible definition of a broader vision of the industry (*e.g.*, develop SRO industry into a gourmet or 'truffle of the sea' industry),

c) a clear definition of activities, responsibilities and time lines that assist achieving the vision and production goal,

d) an outline of where new investment in the industry is expected to come from and areas that will be invested in (*e.g.*, research, human capital development),

e) the development of human capital investment strategies (see section 8.5.1),

f) the development of climate change adaptation strategies (see section 8.5.6), and

g) the development of research priorities and strategies to foster innovation (section 8.5.7).

The review of the current industry development strategies should be undertaken in consultation with all industry members. This will ensure oyster growers understanding of the importance of their participation, contribution and acceptance of such strategies as these should aim to aid the future economic viability of oyster production in NSW and Queensland.

8.5.9 Use of available industry data

During the planning process of the studies in this dissertation it became apparent that limited data about the SRO is publically available. While both key regulatory and management institutions (NSW DPI and QLD DAFF) collect individual production data from oyster farmers on an annual basis, these data sets are unavailable for third parties, due to confidentially agreements between the regulatory authority and oyster farmers. The industry management should look into options to make a better use of the available information in order to inform their decision making processes. For example, the initial intention for Chapter 6 was to undertake a productive efficiency and capacity utilisation analysis for the entire SRO industry. However, the confidentiality agreements in place prevented such an analysis for this dissertation which could have provided more comprehensive information about industry wide production efficiency and capacity utilisation levels as well as potential differenced in their spatial distribution.

8.6 LIMITATIONS OF THE THESIS

The shortcomings of the individual studies in this dissertation have already been discussed in the previous chapters. However, we reiterate the limitations here as they may have affected the key results of this thesis.

A limitation of the socio-economic profile that we described in Chapter 4 was the sample size of only 53 surveys responses which we used for our analysis. The sample represented only 13.5 per cent of oyster growers. As a consequence of the relatively small sample size our results in Chapter 4 may suffer a sampling bias and should be interpreted with caution.

A major shortcoming of the market and demand analysis of Australia’s main commercial oyster species which was presented in Chapter 5 was the length of the time series. For production value and volume there were only 23 observations available for each oyster producing State. The lack of observations and the quality of the data may have affected the quality of the results. Furthermore, we did not assess price relationships between edible oysters and other seafood products offered in Australia. Such an analysis could have provided a broader picture about price formation dynamics that may affect the SRO industry.

There was also a major limitation in the study in Chapter 6, which investigated the impact of demographic characteristics and environmental variable on the productive efficiency of oyster farms in Moreton Bay. In this study we used monthly records to derive annual average values for each environmental variable at each production area. The use of extreme values, such as maxima and minima, would have been more appropriate for our analysis. However, the available monthly data did not provide sufficient information about the frequency and duration of extreme observation. Such information would have been essential for estimating magnitude and significance of extreme environmental observations on productivity in the Bay.

A major weakness of our analysis that examined the impact of climate change and market dynamic on the economic viability of the SRO industry included the use of proxy data in the absence of climate change projections for changes in salinity and estuary water temperature. The constant treatment of production inputs and costs, SRO own-price elasticity and cross-price flexibility with the Pacific oyster, other environmental variables, regulatory framework and dynamics in the Australian seafood market are significant and may have biased the findings of the study in Chapter 7.

8.7 ADDITIONAL FURTHER RESEARCH NEEDS

The work on the studies presented in Chapter 4 and Chapter 6 revealed a general lack of studies in the literature about the socio-economic dimension of aquaculture and fishery management. Available studies in social research on different population cohorts have highlighted that information about the socio-economic composition of specific industries or population cohorts is essential for industry management evaluation and decision-making purposes (*e.g.,* Hudson *et al.*, 2011; Moore, 1991; Sakelliadis *et al.*, 2013). Hence, this could be a field that researchers with an interest in aquaculture and fishery management should consider for further exploration.

Another field which requires more research attention is the role of markets and market dynamics in climate change research for seafood products. Although there has recently been a range of studies published about supply chain adaptation under climate change scenarios (*e.g.,* Fleming *et al.*, 2014; Hobday *et al.*, 2013; Hobday *et al.*, 2008; Lim-Camacho *et al.*, 2014; Plagányi *et al.*, 2014), we believe that a stronger focus on markets, *e.g.,* sea food imports, regulation, exploration of overseas market opportunities; and market dynamics, *e.g.*, time-varying impacts or supply-/demand varying impacts on local producers, can provide seafood industries valuable information that may assist them to better adapt to changing environmental production conditions.

There is currently only limited production cost data available about the industry which needs to be addressed. The lack of production cost data restricts any profitability analysis and consequently does not allow a complete assessment of the industry's future economic viability.

The lack of collected high frequency time series data (*e.g.*, daily observations) for environmental variables in estuaries which we encountered in Chapter 6 is concerning. Monitoring environmental change, particularly due to climate change (*e.g.*, changes to water temperature or changes in salinity), appears to be impossible by collecting and analysing monthly records only. While the collection of high frequency time series data for environmental variables is not a task for the SRO industry the Government should take a lead position in the compiling and analysing such important data in future. Given the potentially high costs involved in the collection and management of such data, a focus on sample sites in selected estuaries may be need to be considered.

8.8 CONCLUSION

The SRO industry has experienced a significant decline in production volume in the past decades. A common perception among the industry's stakeholders is that environmental challenges led to the current state of the industry. This thesis started with the hypothesis that economic dimensions of SRO farming have also contributed to the decline of the industry. The purpose of this dissertation was to enhance the understanding of the economic status quo of the SRO industry. The economic viability of this industry is important since it provides employment and income opportunities in coastal regions of Australia.

The four studies presented in this dissertation validated the hypothesis that not only environmental issues but also economic factors have affected the viability of the SRO industry in the past. We concluded that industry development strategies should not only focus on the environmental sustainability but should equally consider economic dimensions of SRO farming. Based on the individual and combined findings of the four studies undertaking under this research framework a list of recommendations for management and policy enhancement was provided and discussed. The key recommendations included the need for human capital investment, the need for policy makers to cautiously expand the triploid Pacific oyster industry in NSW as well as the need to adjust general industry management strategies (*e.g.*, review of industry development strategies, prioritisation of climate change adaptation, efficient data use, fostering, innovation, and oyster grower participation in industry matters). We have also outlined areas that require further research.

The environmental and economic sustainability of the SRO industry will maximise the benefits from oyster farming for the growers and will also contribute to the economic viability of coastal communities in NSW and Queensland. The findings and recommendations from the research in this dissertation provide information that may assist the industry management and policy decision-making in avoiding management and government failure.

This dissertation provided an integrated economic analysis structure that can be applied to other aquaculture and fishery industries. Most importantly, this thesis proved that environmental sustainability, which most aquaculture and fishery industry strategies currently focus on, is only one part of the puzzle. It is equally important for industry managers and decision makers to consider the economic and social aspects of these industries in order to avoid government failure and the environmental tragedy of the commons.

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Appendices

Appendix A: Chapter 4

Oyster farm survey document for New South Wales

(An identical survey was conducted in Queensland)

PARTICIPANT INFORMATION FOR QUT RESEARCH PROJECT
– Questionnaire –

Economic analysis of the Sydney rock oyster industry in New South Wales

QUT Ethics Approval Number 1200000303

RESEARCH TEAM

Principal Researcher:	Peggy Schrobback, PhD Candidate, Queensland University of Technology (QUT)
Associate Researchers:	Dr Sean Pascoe, Adjunct Professor, QUT and CSIRO
	Dr Louisa Coglan, Senior Lecturer, QUT

DESCRIPTION

This study is being undertaken as part of a PhD research project by Peggy Schrobback. The purpose of this project is to study the productive capacity of the Sydney rock oyster industry. You are invited to participate in this project because you as an oyster grower can provide the most realistic picture of how the farming is done.

PARTICIPATION

Participation will involve completing the enclosed questionnaire which will take approximately 25 minutes of your time. If you agree to participate you do not have to complete any question(s) that you are uncomfortable answering. The full questionnaire is attached for you to look at before you decide to participate. Questions include details on your farming operation, costs of production and your demographic details.

Your participation in this project is entirely voluntary. Your decision to participate, or not participate, will in no way impact upon your current or future relationship with QUT.

EXPECTED BENEFITS

It is expected that this project will directly benefit the industry. The outcome of this study will provide farmers and industry bodies a summary of best practices and the possible demand for operational and institutional improvements to enhance the future productive capacity of the industry.

RISKS

There are no risks beyond normal day-to-day living associated with your participation in this project. It is recommended that research participants of QUT projects who experience discomfort or distress as a result of their participation in the research contact Lifeline on 13 11 14 for assistance.

PRIVACY AND CONFIDENTIALITY

All comments and responses will be treated confidentially. Any data collected as part of this project will be stored securely as per QUT's Management of Research Data Policy. The data may be used for future collaborate projects. In such a case, the data will be treated confidential. The project is funded by the Fisheries Research Development Cooperation (FRDC) and CSIRO. Only the direct project team identified above will have access to the collected raw data. However, access to individually unidentifiable data-subsets may be granted to the funding institutions.

CONSENT TO PARTICIPATE

The return of the completed questionnaire is accepted as an indication of your consent to participate in this project.

QUESTIONS / FURTHER INFORMATION ABOUT THE PROJECT

If you have any questions or require any further information please contact one of the research team members below.

Peggy Schrobback
School of Economics and Finance, QUT Business Faculty
(07) 3138 6675; p.schrobback@qut.edu.au

Dr Sean Pascoe
School of Economics and Finance, QUT Business Faculty
CSIRO Marine and Atmospheric Research
(07) 3833 5966; sean.pascoe@csiro.au

CONCERNS / COMPLAINTS REGARDING THE CONDUCT OF THE PROJECT

QUT is committed to research integrity and the ethical conduct of research projects. However, if you do have any concerns or complaints about the ethical conduct of the project you may contact the QUT Research Ethics Unit on (07) 3138 5123 or email ethicscontact@qut.edu.au. The QUT Research Ethics Unit is not connected with the research project and can facilitate a resolution to your concern in an impartial manner.

Thank you for helping with this research project. Please keep this sheet for your information.

Questionnaire

Economic analysis of the Sydney rock oyster industry in New South Wales

If you have questions or would like assistance in completing the survey, please do not hesitate to contact me, Peggy Schrobback, via telephone: (07) 3138 6675 or email: p.schrobback@qut.edu.au

1 Oyster Aquaculture Lease Information

The following questions will ask about your oyster aquaculture leases. Please provide the data requested in the dedicated fields.

1.1 What is your name:

____

1.2 What is your phone number (may only be used for a follow up interview):____

	Please add your oyster **aquaculture lease numbers** & **name of estuary** (e.g. AL075 or AL253, Clyde River or Wallis Lake)				
1.3 What oyster aquaculture leases do you currently hold?					
1.4 What are the total hectares of each lease?					
1.5 Which of these oyster aquaculture leases are active sites? (Please tick the appropriate oyster lease in the left-hand fields)					
1.6 Which of the active oyster aquaculture leases are sites where one or more of the activities listed below are taking place? (Please tick to the appropriate oyster lease in the left-hand fields)					
a) Catching ground / spat collection					
b) Nursery					
c) Grow-out					
d) Finishing (prior to market)					

1.7 Have you worked other oyster aquaculture leases over the past 10 years that you no longer operate? ☐Yes ☐No

If yes, what were the reasons for changing the lease?

____

1.8 Have you bought or leased any new oyster aquaculture leases over the past 10 years? ☐Yes ☐No

1.9 Are you interested in obtaining additional oyster aquaculture leases? ☐Yes ☐No

2 Farming Practice & Stock Maintenance

The following questions will ask about your farming practices and stock maintenance. Please provide the data requested in the dedicated field for the financial year 2011/12.

2.1 Origin of seed	Number of seed	Cost of seed ($)	Origin (QLD/NSW)
Wild			
Hatchery (from wild seed)			
Hatchery (selectively bred stock)			
Total spat cost			
Seeding period			

2.2 Farming method:	Please add your oyster aquaculture lease numbers (e.g. AL075 or AL253)				
Basket					
Tray					
Long-lines					
Sticks					
Sub-tidal (rafts)					
Surface floating (bags)					
Please indicate other methods used below:					

2.3 Grow-out:	Percentage of seeded stock
Grow-out rate (harvested stock)	
Mortality rate	
Main reasons for mortality	

3 Farming Inputs

The questions in this section will ask you about inputs in oyster farming and its costs. Please provide the data requested in the dedicated field for the financial year 2011/12.

3.1 On Farm Assets	**Type**	**Number of Units**	**Purchase Price per Unit ($)**	**Year of Purchase**	**Asset financed (Yes / No)**	**Replacement planned in... (Year)**
Baskets						
Trays						
Long-lines						
Grader						
Cooling system						
Other processing equipment						
Boats / barges						
Other machinery (e.g. tractor, ute, etc.)						
Building structures (e.g. storing shed, land, etc)						
Other assets (please list here)						

Note: If purchase price not available anymore, please fill in the remaining fields.

3.2 Did you use any hired equipment in 2011/12? ☐Yes ☐No

If yes, what type of equipment was hired?

____

If yes, what was the total cost of hired equipment? $________________________________

Is the equipment hired each season? ☐Yes ☐No

3.3 What were your estimated operational costs in 2011/12?

Fuel and oil (boat, tractor, car): $ ____

Water sampling: $ ____

Repairs and maintenance: $ ____

3.4 What were your estimated administration costs in 2011/12?

Insurance: $ ____

Permit / licence fees: $ ____

Other admin costs (e.g. Marketing / office expenses, electricity, vehicle registration costs, etc.):

$ ____

Land lease (for onshore activities): $ ____

Bank fees and interest paid: $ ____

3.5 What were your estimated post-harvest costs in 2011/12?

Transport and logistics: $____

Packaging: $____

Other cold storage (e.g. ice): $____

3.6 Labour	Employed workers				Unpaid workers (including owner-operator and family)
	Number of employed workers	**Average number of working hours / week**	**Labour costs per hour or per annum**	**Length of employment in weeks**	**Number of working hours / week**
Full-time employed					
Part-time employed					
Casual / seasonal employed					

3.7 What are the estimated total labour costs in 2011/12?

$____

Do the total labour costs include your income? ☐Yes ☐No

4 Farming Outputs

Please complete the following table to indicate the main harvesting periods and the quantity and size of the harvested stock in season 2011/12.

Note: This question only applies to oysters that have reached their final harvest and are being sold as food.

4.1 Harvest period	Grade	Dozen
July 2011		
August 2011		
September 2011		
October 2011		
November 2011		
December 2011		
January 2012		
February 2012		
March 2012		
April 2012		
May 2012		
June 2012		

4.2 Have there been any closures of your leases during the season? ☐Yes ☐No

If yes, in which month(s)? ____

If yes, what were the reasons for the closure(s)? ___________________________

What was the average farm gate price for the different product grades in the last harvesting season? Please complete the following table.

4.3 Price per grade	**Average price (in $/dozen) Shucked**	**Average price (in $/dozen) Unshucked**
Bottle		
Bistro		
Plate		
Other (indicate): _____________		

5 Markets

The following questions will ask you about the market range of your products and marketing tools. Who do you sell your products to? To answer this question, please complete the following table.

5.1 Market range	Percent of total production
Wholesalers	
Processors	
Direct sale to end costumer:	
- On farm sale (e.g. own restaurant on farm)	
- Restaurants, hotels, fish shops:	
- Local (10 km range to farm)	
- Sydney	
- Other NSW	
- Interstate	
- Export	

5.2 Is the access to markets / customers an issue for your business? ☐Yes ☐No

5.3 What marketing or promotional tools do you use in your business?

Participation in seafood festivals/food exhibitions: ☐Yes ☐No

Own business website: ☐Yes ☐No

Acquisition of new customers by pamphlets / business cards: ☐Yes ☐No

Other: ☐Yes ☐No

5.4 Would you support a pooling of marketing and promotion on behalf of oyster growers in your region in order to access markets more easily? ☐Yes ☐No

6 Environment

In this section you will be asked about environmental issues that may affect your business. Please provide the data information for the financial year 2011/12.

6.1 How often do you undertake oyster meat/water quality testing per month?

____

6.2 What are environmental issues affecting oyster production?	**Strongly disagree**	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
Boat traffic					
Sewage overflows					
High rainfall events					
Other reason:_________________					
Other reason:_________________					
Other reason: ________________					

6.3 Do you believe that the quality of your products has declined over the past years due to environmental issues?

☐Yes ☐No

7 Restrictions to Expansion of Production

Questions in this section will ask you about possible restrictions that may affect production of oysters.

Listed below are statements describing potential constraints to expanding of oyster production.

For each statement, please 'X' the field which best describes how strongly you agree or disagree with the statement. For example, if you strongly agree then 'X' the Strongly agree field. Remember, to 'X' one field for each statement.

7.1 Restrictions to oyster production arise due to ...	**Strongly disagree**	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly agree**
the availability of seed					
the cost of seed					
availability of leased land (ground)					
availability of oyster leases					
the lack of a markets or low product prices					
problems with predators					
problems with diseases					
inadequate water quality/ environmental conditions					
stock theft					
lack of training					
lack of cooperation among oyster farmers in the region					
ineffective bodies (e.g. Oyster Grower Association, state authorities) in supporting oyster farming					
inappropriate emergency response strategies (e.g. in the case of an disease outbreak)					
Other reason:__________________					
Other reason:__________________					
Other reason: _________________					

7.2 What do you think are the future development prospects of the Sydney rock oyster industry in New South Wales under current industry management?

____

____

____

____

7.4 Suppose state regulation would permit the introduction of the Pacific oyster to all estuaries in New South Wales, would you diversify your production by growing Pacific oysters?

☐Yes ☐No

If yes, please indicate the proportion by which you would diversify your total production:

______% Sydney rock oysters

______% Pacific oysters

If yes, would you grow diploid or triploid Pacific oysters? ☐Diploid Pacific oysters

☐Triploid Pacific oysters

8 Information about oyster farmers

In this section some information about yourself will be ask for statistical purposes.
Please tick the appropriate box or provide the data requested.

8.1 What is your gender? ☐Female ☐Male

8.2 What is your age? ____

8.3 What is your country of birth? ____

8.4 What is the number of years that you worked in oyster farming? ______________________

8.5 Are you the first generation within your family farming oysters? ☐Yes ☐No

If no, for how many generations has your family been in oystering? ____________________

8.6 How many persons live in your household? _____________________________________

8.7 How many children do you have? ____

8.8 What is your annual income?

☐$0 – $40,000
☐$40,001 – $60,000
☐$60,001 – $80,000
☐$80,001 – $100,000
☐$100,001 – $120,000
☐Over $120,000

8.9 Do you receive income from off-farm activities? ☐Yes ☐No

If yes, what proportion of your income comes from oyster farming?___________________%

8.10 Are you a member of a growers association? ☐Yes ☐No

8.11 Have you attended any trainings, workshops or industry information sessions in the past year? ☐Yes ☐No

8.12 Do you have experience in farming other fish / shellfish species? ☐Yes ☐No

If, yes, please indicate which fish / shellfish species? _________________________________

8.13 What it the post code of your residential address?___________________________________

8.14 What is your highest level of formal education?

☐Year 10 certificate and below
☐Year 12 certificate
☐TAFE degree / Apprenticeship
☐University degree

8.15 Are you interested in receiving a summary of this research? ☐Yes ☐No

Thank you very much for you participation.
Please return the questionnaire by mail using the provided envelope.

Appendix B: Chapter 4

Selected responses from farmers about future prospects of the SRO industry

"A gradual decline as profitability declines. This decline could accelerate if environmental factors worsen." (Part-32)

"I think the SRO industry will slowly die due to the Pacific oyster taking an ever increasing market share. The SRO may become the truffle of the sea, scarce & expensive." (Part-44)

"Good, if they can keep the Pacific oysters out. The taste of SRO is much better that is what you get from customers. Commercially, the POs (for Pacific oysters) are much more attractive. If the PO is brought in on larger scale, SRO will vanish slowly." (Part-46)

"Limited information available on consumer demand/possible prices as processors are in the way, something needs to be done on the marketing of the SRO, the SRO is premium product, industry is divided about marketing of the product, water quality is an issues that may limit production in future, high potential for export of live product into wealthy developing countries such as China / Dubai" (Part-49)

"The SRO is a great product but with costs, Fisheries, Food Authority, local gov., lands department plus processors slow paying or not paying at all doesn't help." (Part-42)

"Access & supply to hatchery stock is an issue, demand is there and increasing, issues come from rain/closures." (Part-43)

"Farmers are walking away because of high fees & charges for small operators." (Part-3)

*"With research & some assistance from state government the prospects could be very good."(*Part-4)

"Prospects good if water quality can be maintained. Diversity of culture species. Lack of will & ineffective management of catchment areas by GC (for Gold Coast) City council & State and Federal Environmental Departments to oversee proposed and existing risks, more about being seen to be 'in control' than being in control." (Part-9)

"The labour intensity of the industry makes the business unviable. A 4 year growing period is twice that of Pacifics." (Part-14)

"Under current industry management the seafood fees are astronomical and with more regulations make the oyster industry unattractive to new investors, also the product is only available for a few months of the year." (Part-15)

"Due to limited harvest times (4 months only) buyers want continuity of supply all year round, cannot do this with rocks only." (Part-24)

"Something needs to be done for farmers to get better and quicker information, too much red tape." (Part-25)

"I think the industry will boom with export markets." (Part-27)

"Enhanced disease prevention and management, greater availability of affordable, high quality hatchery seed, greater emphasis on the importance of local ecosystem conservation [....]. The industry is not doing too well at the moment with the flood events up in the northern estuaries but with a bit of fresh wind and enthusiasm that can be changed." (Part-33)

"Industry is going through a tough period due to several years of heavy rain. Price needs to be increased, one option could by through exporting oysters." (Part-39)

"*NSW and the eastern seaboard have experience the wettest period in a long time. Hopefully the industry as a whole will be boasted in production & management in future. Administrative costs are high and increasing. It is difficult for farmers to find markets at which they can get a good price. Cooperative systems of marketing did not work before so prospects are not good*." (Part-40)

Appendix C: Chapter 7

Table 7.A: Results of the revenue function estimation (equation 3)

Coefficient	Estimate	Std. Error	p-value
(Intercept)	-0.8668	0.5033	0.0856
Plate price	0.3405	0.0107	0.0000
Bistro price	0.3363	0.0063	0.0000
Bottle price	0.3232	0.0098	0.0000
Plate price squared	0.0066	0.0280	0.8125
Bistro price squared	0.0650	0.0356	0.0683
Bottle price squared	0.1317	0.0708	0.0635
Plate price and bistro price	0.0300	0.0345	0.3853
Plate price and bottle price	-0.0366	0.0344	0.2878
Bistro price and bottle price	-0.0950	0.0496	0.0557
Area	0.5807	0.5445	0.2867
Farmers	1.5439	0.3413	0.0000
Temperature	-0.1958	0.5929	0.7413
Salinity	0.4933	0.5308	0.3531
Area squared	1.3936	0.4198	0.0010
Farmers squared	-1.1628	0.5038	0.0214
Temperature squared	-10.5305	3.4904	0.0027
Salinity squared	-1.0008	0.6311	0.1134
Area and farmers	1.9447	0.8496	0.0225
Area and temperature	-1.2517	1.0365	0.2277
Area and salinity	1.7658	0.7342	0.0165
Farmers and temperature	3.5220	1.6061	0.0288
Farmers and salinity	-1.4171	1.1522	0.2193
Temperature and salinity	-13.0212	3.7887	0.0006
Plate price and area	0.0326	0.0225	0.1479
Plate price and farmers	-0.0736	0.0318	0.0212
Plate price and temperature	-0.0488	0.0530	0.3580
Plate price and salinity	0.0897	0.0494	0.0703
Bistro price and area	0.0072	0.0135	0.5955
Bistro price and farmers	-0.0399	0.0192	0.0379
Bistro price and temperature	-0.0049	0.0313	0.8758
Bistro price and salinity	0.0376	0.0291	0.1968
Bottle price and area	-0.3428	0.7275	0.6377
Bottle price and farmers	0.4325	0.9841	0.6605
Bottle price and temperature	-1.0595	1.7305	0.5406
Bottle price and salinity	0.9698	1.5316	0.5269
R1	-3.3185	1.9138	0.0835
R2	-2.8485	1.7082	0.0960
R3	1.0767	0.8029	0.1805
R4	0.2425	0.7243	0.7379
R5	0.9523	0.6685	0.1549

Continued Table 7.A in Appendix C

R6	1.7203	0.5910	0.0038
R7	-0.1184	0.4129	0.7745
R9	-6.0725	0.6159	0.0000
R10	-4.5272	1.6549	0.0064
R11	1.0102	0.6240	0.1061
R12	-1.2046	0.4349	0.0058
R13	-7.3906	2.2505	0.0011
R14	1.0180	0.4458	0.0228
R15	1.5616	0.3868	0.0001
R16	1.0305	0.5729	0.0726
R17	1.3595	0.6762	0.0449
R18	0.3089	0.7296	0.6722
R19	1.3074	0.4907	0.0080
R20	0.9384	0.6503	0.1496
R21	-0.7391	0.9293	0.4268
R22	-5.8261	0.6435	0.0000

Notes: Regression statistics: Residual standard error: 0.446 on 134 degrees of freedom, number of observations: 191, degrees of freedom: 134, adjusted R-squared: 0.864.
The results presented in this table are based on equation 7.3. Coefficients with a significance level of up to 10 per cent were used to derive the revenue elasticities described in equation 7.6 and 7.7. For example, to derive the revenue elasticity with respect to temperature the following coefficients were used: 'Temperature squared', 'Farmers and temperature' and 'Temperature and salinity'. These coefficients were then multiplied with the normalized mean value for the respective single or interaction-term variable. The obtained results are shown in Table 7.4.