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Review

History, status and future of Australia's native Sydney rock oyster industry

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Abstract – The Sydney rock oyster (*Saccostrea glomerata*) (SRO) is an oyster species that only occurs in estuaries along Australia's east coast. The SRO industry evolved from commercial gathering of oyster in the 1790s to a high production volume aquaculture industry in the 1970s. However, since the late 1970s the SRO industry has experienced a significant and continuous decline in production quantities and the industry's future commercial viably appears to be uncertain. The aim of this study was to review the history and the status of the SRO industry and to discuss the potential future prospects of this industry. This study summarised findings of the existing literature about the industry and defined development stages of the industry. Particular focus was put on the more recent development within the industry (1980s-present) which has not been covered adequately in the existing literature. The finding from this study revealed that major issues of the industry are linked to the management of prevailing diseases, the handling of water quality impairments from increasing coastal development, increasing competition from Australia's Pacific oyster (*Crassostrea gigas*) industry and the current socio-economic profile of the industry. The study also found that policy makers are currently confronted by the dilemma of saving a "dying art". Findings from this industry review may be vital for current and future fisheries managers and stakeholders as a basis for reviewing industry management and development strategies. This review may also be of interest for other aquaculture industries and fisheries who are dealing with similar challenges as the SRO industry.

Keywords: Sydney rock oyster / Aquaculture / Pacific oyster / Industry / History / Australia

1 Introduction

The Sydney rock oyster (*Saccostrea glomerata*) (SRO) is a native Australian oyster species. This oyster species only occurs in estuaries along the New South Wales (NSW) and south-east Queensland coasts (Fig. 1).

The development of the SRO industry can be traced back to early European settlement along Australia's east coast. Although evidence exists that SROs were gathered and consumed by Australia's Aboriginal people dating back well before European settlement (Attenbrow 2002). Up until the 1870s, the unregulated gathering of oysters and oyster shell by the first settlers led to a serious decline in oyster banks and reefs. Legislation regulating the gathering of oysters was introduced in Queensland in the 1860s and in NSW in the early 1880's and laid the foundations for the development of a commercial oyster industry (NSW Royal Commission on Oyster Culture, 1877). Until the late 1970s this industry experienced periods of high growth with production peaking in the 1970s. Since the 1970s, SRO production has been in decline. This has been attributed to outbreaks of oyster diseases, public health safety issues associated with the contamination of estuarine waters, increasing production costs (White 2001).

Another factor has affected the economic viability of the SRO industry is development of the Pacific oyster (*Crassostrea gigas*) industry in Australia's (Schrobback et al. 2014a). The Pacific oyster is not native to Australian waters and was deliberately introduced to Tasmania in the 1950s (Mitchell et al. 2000) and to South Australia in the late 1960s (PIRSA 2003). The Pacific oyster industry now accounts for about 72% of total edible oyster production volume (ABARES 2013) and is responsible for the increase in the national oyster production since the late 1990s a period over which the production of SRO decreased slightly (ABARE 1991; ABARES 2013).

The Pacific oyster industry also poses a tenable environmental threat to SROs. Although the spatial distribution of the Pacific oyster is regulated by fisheries legislation in each State, due to this species' invasive behaviour (Medcof and Wolf 1975; Pollard and Hutchings 1990), its spread to SRO growing area could not be prevented. Wild Pacific oysters have been found in SRO production areas since the 1960s. The displacement of SROs by wild Pacific oysters led to a

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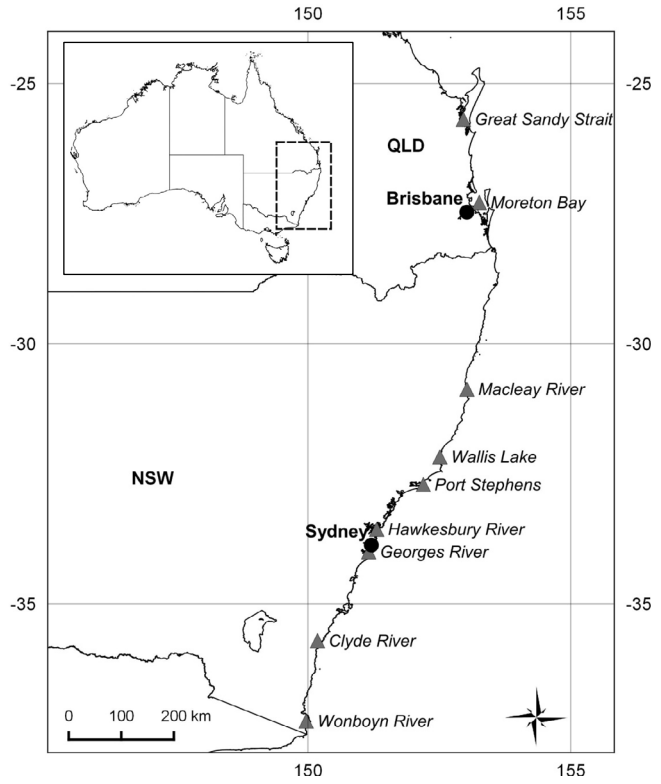

Fig. 1. Selected Sydney rock oyster (SRO, *Saccostrea glomerata*) production areas in New South Wales (NSW) and Queensland (QLD). Wonboyn River represents to southern most estuaries of past and current SRO production areas; Great Sandy Strait represents the past northern most production area, current northern most cultivation area is Moreton Bay. Other estuaries pictured in the map are referred to in the text which represents only selected estuaries of currently 41 active oyster production estuaries.

detrimental environmental and financial impact on affected SRO farming communities (Clarke 2013). In order to keep SRO farmers in business whose stocks had previously been affected by diseases or wild Pacific oyster infestation, authorities in NSW now permit the production of wild and triploid Pacific oysters in a limited number of estuaries and under strict environmental obligations. The Pacific oyster grows faster to reach a marketable size and has a larger temperature tolerance than the SRO; therefore it is often considered as the superior commercial species.

A further potential environmental challenge to SRO cultivation comes from climate change. The impact of predicted increases in annual sea surface temperatures along the east coast of Australia (CSIRO and BOM 2014), changes in the acidity (pH) or salinity may affect the future productive capacity of the industry. Thus, adaptation to changing oyster production conditions may be necessary.

Today, the SRO industry is relatively small within Australia's aquaculture sector that produced about 4500 metric tons of oysters in 2012 valued at approximately 28.8 million Australian dollars, which accounts for about 40% of Australia's total oyster industry production value (NSW DPI 2011; ABARES 2013; Wingfield and Heidenreich 2013).

Whether the SRO industry in its current form has the capacity to remain commercially viable against today's challenges is unclear. However, the future of the SRO industry does pose an interesting dilemma for society and policy makers. At one extreme it is an industry of historical significance and as such a case may be made for protecting the cultivation of this native oyster based on cultural and heritage values. At the other extreme, the industry may choose to replace the SRO with non-native oyster species which are commercially more attractive to cultivate but may jeopardise the long-term existence of the native species.

The aim of this study was to provide a review of the history and the status of Australia's native SRO industry as well as a discussion of its potential future. 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. This study aimed to summarise the findings of these authors and to identify development stages of the industry. Furthermore, this study focused on the more recent developments of the industry which has not been covered adequately in the previous reviews.

Information from the assessment of the industry and the discussion of the findings from this study may be vital for current and future fishery managers and stakeholders as a basis for reviewing management and development strategies and future industry prospects. The present industry review may also be of interest for stakeholders in other aquaculture and fisheries who are dealing with similar challenges as the SRO industry.

2 Review of industry development stages

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

The development of the SRO industry can be categorised into five stages (Fig. 2). Each of these stages will be described in the following sections.

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 (Smith 1985; Lergessner 2006). Archaeological evidence of shell midden, confirming that Aboriginals in coastal communities continuously collected and consumed native oysters in the northern estuaries of NSW, date back to approximately 1720 BP (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). 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). 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 is rated as relatively benign, most likely because of low human population density (Bailey 1975; Attenbrow 2002).

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

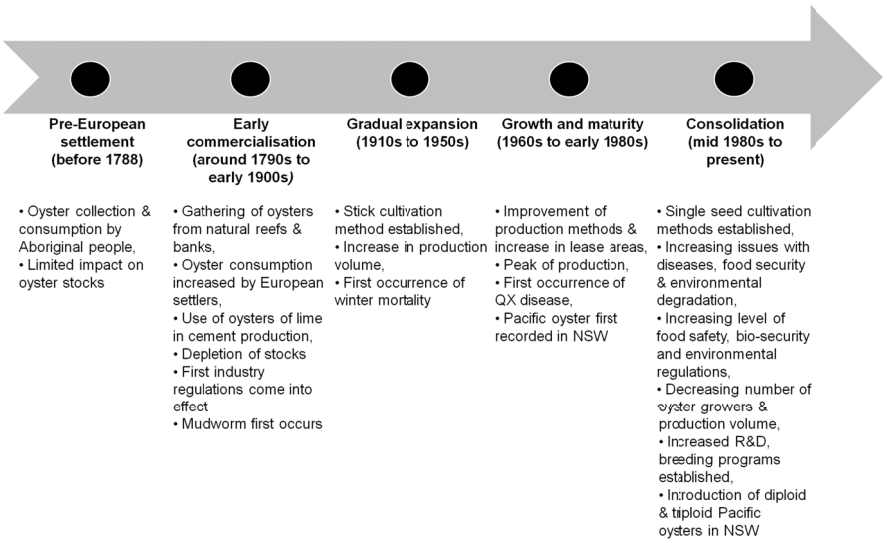

Fig. 2. Development stages of the Sydney rock oyster industry.

2.2 Early commercialisation (around 1790s to early 1900s)

Large scale gathering of SROs began in the late 1700s north of Sydney soon after the European settlement in NSW (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) (Smith 1985). Dredge oysters were collected by means of a dredging basket operated from a boat (Smith 1981; Smith 1985). Dredge oysters were claimed to grow faster, taste better and sell for higher prices (Smith 1981, 1985). Harvesting bank oysters was simpler since it involved the collection of oysters occurring naturally attached to stones and dead oyster shells (Smith 1981). These oysters were handpicked, either off the ground or off the oyster reefs (Smith 1985). By the 1860s oysters were used for consumption and as a source for lime in cement production (Smith 1981; Lergessner 2006)[2].

A rapidly increasing population of European settlers in NSW soon resulted in the overexploitation of the intertidal and sub-tidal reefs and banks (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 (Smith 1985). Queensland also provided spat to the NSW oyster industry at that time (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 (Smith 1981; Smith 1985).

Concerns about the overexploitation of natural oyster beds during the 1850s, 1860s and 1870s led to government regulations being implemented in Queensland and NSW aiming to protect 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 (NSW Royal Commission on Oyster Culture 1877; Smith 1981; Smith 1985; Lergessner 2006; Ogburn 2011). 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 in 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 is was necessary to secure the spat (NSW Royal Commission on Oyster Culture, 1877). The findings of the Royal Commission resulted in the *Fisheries and Oyster Farms Act 1884* in NSW.

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; Smith 1985).

In 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, due to the blisters it formed within the oyster shell, 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 to total of approximately 5000 bags (approximately 313 metric tons)[3] 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

[2] Live oysters were piled in heaps or in lime-kilns and burned to lime, which was used to make mortar for construction of buildings (Smith 1985).

[3] One bag equals approximately 62.5 kg.

the early 1970s, whereas a century earlier in the 1870s mudworm had become widespread along eastern Australian coasts (Read 2010).

The average value of a bag (approximately 62.5 kg) of oysters 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 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 7000 bags (approximately 438 metric tons) of oysters and increased to over 20 000 bags (approximately 1250 metric tons) after the first mudworm crisis at the end of the century (Ogburn et al. 2007). In Queensland, leased oyster areas expanded to a total of about 2751 hectares in 1886 (Smith 1981). The production volume (Moreton Bay and Sandy Strait areas only) peaked in 1891 with about 21 000 bags (about 1313 metric tons), which were mainly exported to lucrative southern markets such as Melbourne, Sydney and also to Perth (Smith 1981; Lergessner 2006).

2.3 Gradual expansion (1910s to 1950s)

Oyster farmers noticed that oysters growing on elevated structures above the ground grew faster and were less susceptible to mudworm infestation. 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 found 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). The depletion of suitable black mangrove sticks by the 1940s led to the development of the coal tared sawn hardwood stick (Clarke 2013). These readily available and easy to handle oyster sticks laid the foundation for the rapid expansion of the industry during the 1950s, 1960s and 1970s (Clarke 2013)[4]. However, similar to the black mangrove sticks, the coal tared 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 the parasite *Mikrocytos roughleyi*, were reported from the Georges River (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 during this period increased gradually to about 5140 metric tons of oysters by the end of the 1950s (Fig. 3) (Pease and Grinberg 1995). Major oyster producing estuaries during this period included Port Stephens, Georges River and Hawkesbury River (Fig. 1).

Although the oyster production in NSW recovered quickly from mudworm infestation and winter mortality at the beginning of the century, the industry in south-east Queensland significantly decreased during this period (Smith 1981; Lergessner 2006). Until the 1920s the oyster industry in Morton 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 workers and 665 oyster banks (see bank oysters above) were involved in Queensland's oyster industry during 1911–1920 (Lergessner 2006). The decline in oyster production in Queensland was linked to the mudworm infestation[5], 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 (Smith 1981, 1985; Lergessner 2006). The lack of infrastructure investment was partly due to a lack of security of oyster bank tenure with licences renewed annually and only six months eviction notice required (Smith 1985)[6].

2.4 Growth and maturity (1960s–early1980s)

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

During this period it was common to transfer oyster 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. It is estimated that around 75% of all oysters harvest in NSW originated from Port Stephens (Ogburn 2011).

Food safety issues from contaminated shellfish became an increasingly public concern during the 1960s and 1970s. For example, in 1978 an incident involving over 2000 reported cases of viral gastroenteritis (due to a norovirus, "Norwalk virus") was linked to the consumption of oysters farmed in the Georges River (Murphy and Grohmann 1978; Grohmann et al.

[4] 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).

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

[6] 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 undertaking either by auction or tender (Smith 1985).

1980; Linco and Grohmann 1980). In response to this incidence, depuration[7] of oysters for a period of seven days prior to sale became compulsory in 1983 (Ogburn 2011), and recently, the need for future norovirus control measures for shellfish (Brake et al. 2014). This health and food safety risk management approach was the sole in place and believed to provide sufficient protection to oyster consumers (Ogburn 2011).

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 2013). 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 and Dove 2009). A recent review article described the threats from infectious diseases in aquaculture and the QX disease in SROs (Raftos et al. 2014).

During this development stage of the SRO industry, first reports of the habitat invasive Pacific oyster were made in Pambula River, southern NSW, in 1967 (Wolf and 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 and Medcof 1974). Due to the potentially negative impact of Pacific 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 and Medcof 1974). The industry management reacted with restricting transfers of oysters to the northern estuary thereafter to prevent the spread of Pacific oysters with limited success as next development stage of the industry will show (Nell 2001).

NSW oyster production peaked in the mid-1970s with a production volume of about 9970 metric tons of oysters per annum (Pease and 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 (Smith 1985; Lergessner 2006).

3 Consolidation (mid 1980s-present)

3.1 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 in 1993/94 and in the Hawkesbury River in 2002/03 and 2003/04 collapsed due to the QX disease. Other estuaries, such as the Tweed, Richmond and Macleay Rivers, continued to be affected till this day (Ogburn 2011). Since the disease appeared to have become endemic, SRO production was abandoned in Georges and Hawkesbury Rivers (north of Sydney). The precise cause of the occurrence of the parasite and how it effects SROs remains unclear. However, environmental and nutritional factors are believed to contribute to the parasite's ability to infect the oyster, and the oysters ability to defend itself from the parasite (NSW DPI 2013). 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, however production remains small at this stage.

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% on average, and in extreme localised cases losses of up to 90% (Steven McOrrie, pers. comm. 2013). The exact cause for winter mortality remains unknown but environmental factors provide a partial explanation for the disease (Spiers et al. 2014).

Mudworm infestation is nowadays controlled by well established stock management practices (Steven McOrrie, pers. comm. 2013). Other factors that can also result in significant losses of SRO stocks are heat kill (Ogburn 2011) and algal blooms (Diggles 2013).

3.2 Environmental concerns

The SRO industry has also been affected by increasing catchment and coastal development in recent times (O'Connor and Dove 2009). A decline in water quality caused 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 and Dove 2009). As a consequence of 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 2014), 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.

The impact of the oyster cultivation on estuary health 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

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

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 on derelict leases has resulted in high disposal costs for both industry and government in NSW and Queensland States (Katie Sachs, NSW Department of Primary Industries, pers. comm. 2013). As a consequence, the *NSW Fisheries Management Act 1994* requires now the lodgement of environmental performance bonds covering oyster lease areas held by individual oyster farmers. To ensure compliance with the oyster farmer's responsibilities under the *NSW Fisheries Management Act 1994*, NSW DPI conducts lease inspection audits of all leases in the State once every three years. Failure to comply with the compliance directions can result in fines or remediation by NSW DPI. 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 increasingly participate 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.

Recurrent and unprecedented flood events, in the recent past, had a significant impact on oyster farming businesses, particulary in estuaries located north of Port Stephens (Steven McOrrie, pers. comm. 2014). It is expected that the prospects of climate change with warming sea surface temperatures and an increase in severe weather events (CSIRO and BOM 2014) in south-east Queensland and NSW are likely to affect the industry in future (Leith and Haward 2010). Yet, the industry currently lacks an assessment of the potential risk of climate change to SRO production and climate change adaptation strategies.

3.3 Pacific oyster in NSW

Port Stephens initially remained the main oyster nursery hub for the entire SRO industry (O'Connor and Dove 2009). However, this came to an end in the mid 1980s with the infestation of the Port Stephens estuary by Pacific oysters, *Crassostrea gigas* (O'Connor and Dove 2009). In 1986, Pacific oysters were declared a noxious fish in all NSW waters except in Port Stephens and control measures were put in place to limit the spread of Pacific oysters to other estuaries. 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). Due to the overwhelming numbers of wild Pacific oysters present at Port Stephens, their cultivation was there permitted in the early 1990s (Steven McOrrie, pers. comm. 2013). Production of Pacific oysters in the Port Stephens estuary was about 2720 bags (approximately 170 metric tons) in 2011/12 (NSW DPI 2013). 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 (NSW DPI 2012).

Following the completion of favourable environmental impact assessments[8], the NSW DPI, (the industries' management authority in NSW), approved the cultivation of triploid Pacific oysters[9] in the Georges and Hawkesbury Rivers in 2004 and 2005 respectively. In both rivers 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 (Fig. 1). This indicates that SRO growers have already started to diversify their production. Triploid 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 which are not affected by QX disease are of particular commercial interest for oyster farmers since they grow significantly faster than the native SRO and thus reach earlier a marketable size (Nell and 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)[10] affected populations of wild Pacific oysters in Port Jackson/Sydney Harbour and wild and farmed triploid Pacific oysters in the Georges River and Botany Bay (NSW DPI 2014). In early 2013, POMS has been detected in farmed triploid Pacific oysters in Hawkesbury River (NSW DPI 2014).

In 2011/12 the production volume of triploid Pacific oysters in NSW was about 5463 bags (approximately 341 metric tons) valued at 2.7 million Australian dollars (NSW DPI

[8] An environmental assessment is an assessment of the environmental impacts of aquaculture activities 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.

[9] 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. Triploid Pacific oysters are functionally sterile and have extremely low propagation rates and are considered non-invasive (Gong et al. 2004).

[10] The Pacific Oyster Mortality Syndrome (POMS) is a diseases caused by a virus called OsHV-1 micro variant (Paul-Pont et al. 2013; Green et al. 2014). This disease affects 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).

2003). Today, SRO growers remain much divided about the increasing introduction of triploid Pacific oyster as a recent survey of the industry revealed (Schrobback et al. 2014b). Yet, the ramification of the introduction and management of the wild Pacific oyster in NSW remains significant for the SRO industry, economically and politically (Ogburn 2011). In Queensland, any Pacific oyster production remains prohibited to date. By allowing the cultivation of triploid Pacific oyster industry in NSW the industry management successfully saved oyster businesses that were affected by QX disease (mainly Hawkesbury and Georges Rivers). However, the decision to diversify the NSW oyster aquaculture by expanding Pacific oyster production in this State may have also contributed to additional pressure on the remaining SRO growers in a market in which both species compete with each other (Schrobback et al. 2014a).

3.4 Innovation in production methods

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. A selective breeding program[11] for SRO spat in hatcheries was established by NSW DPI in 1990 with the aim of selecting SRO 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 and Dove 2009). The breeding program is currently co-funded by the oyster industry and the 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 seed was estimated at around 40 million spat, which equates to around 30% of current industry demand (O'Connor and Dove 2009). The financial outlay of hatchery spat is considerably larger than for natural spat and may, therefore, not be affordable for all growers. Yet, issues with diseases in wild oyster stocks caused selectively bred stock to become more attractive (Nell 2001).

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. 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 is 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. The oyster furniture is then transported to areas of low spatfall for maturing (Ogburn 2011).

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

Advantages of single-seed cultivation include improved shape and growth of oysters. However, this cultivation methods 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.

3.5 Market and production scale

In the past decade the SRO industry has been facing increasing competition from an expanding Pacific oyster industry in Tasmania and particularly in South Australia from the early 1990s. Pacific oysters were deliberately introduced to Tasmania in the 1950s (Mitchell et al. 2000) and to South Australia 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). Pacific oyster cultivation in Australia remains based on hatchery stock. 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 South Australia (Trudy McGowan, South Australian Oyster Growers Association, pers. comm. 2011). Since 2004, the supply of Pacific oysters exceeds the market supply of SROs (Fig. 4). Pacific oysters are mainly sold domestically. While the market share of SRO production was 70% in 1989, it is now the Pacific oyster production that holds the same share in the Australian oyster market (Schrobback et al. 2014a).

The evolution of farm gate prices of SROs and Pacific oysters in Australia shows that SROs have attracted a higher price per kilogram over time (Fig. 5). Increases in prices for SROs since 2004 may reflect the increased scarcity in SRO supply over the same period and a relatively stable demand.

Schrobback et al. (2014a) recently provided empirical evidence that SRO and Pacific oysters compete in the same economic market and that prices of SROs have come under pressure by an increase of Pacific oyster production volume. These findings imply that SROs could have attracted higher prices without increasing competition from the Pacific oyster industry.

The proportion of SROs sold as larger size "plate" reduced in favour of smaller "bistro" and "bottle" grade oysters (O'Connor and Dove 2009). Explanations for the trend towards the sale of smaller oysters do not only include changes in demand (O'Connor and Dove 2009). It is likely that farmers used changes to their oyster production mix as a strategy to deal with increased stock loss risk and to maintain their business cash flow in the short term particularly on the NSW south coast where the risk of winter mortality is high.

As a consequence of both, environmental challenges and increasing competition from the Pacific oyster production, the SRO industry saw a significant reduction in output during its latest development stage. The production volume in NSW decreased from about 9250 metric tons in 1980 to about 4500 metric tons in 2012 (Pease and Grinberg 1995; NSW DPI 2013) (Fig. 3). In Queensland, a similar trend was observable, while the production volume was about 245 metric tons in 1989 the production output declined to approximately 85 metric tons in 2012 (ABARE 1991; Wingfield and Heidenreich

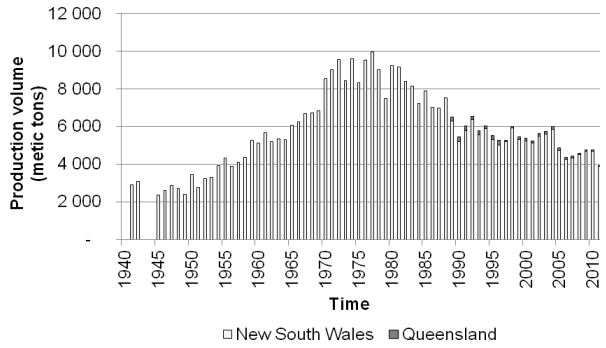

Fig. 3. Sydney rock oyster annual production volume over time. Data for 1940, 1943 and 1944 not available for NSW production. Data for the period 1940–1989 not available for Queensland. Source: Data for the period 1941–1992 retrieved from Pease and Grinberg (1995), data for period 1993–2012 from ABARE (1993–2009), ABARE-BRS (2010), and ABARES (2011–2013).

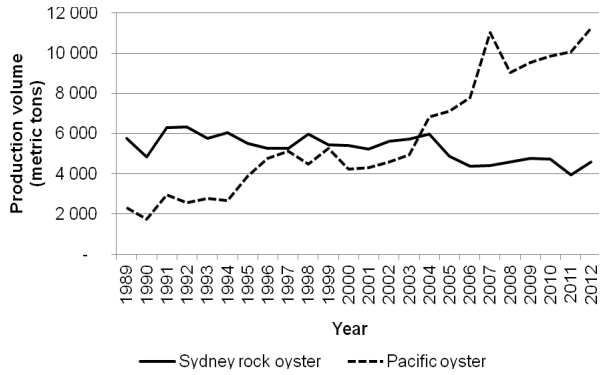

Fig. 4. Evolution of Sydney rock oyster and Pacific oyster production volume in Australia. Source: ABARE (1991, 1993–1997, and 1999–2009), ABARE-BRS (2010), ABARES (2011–2013).

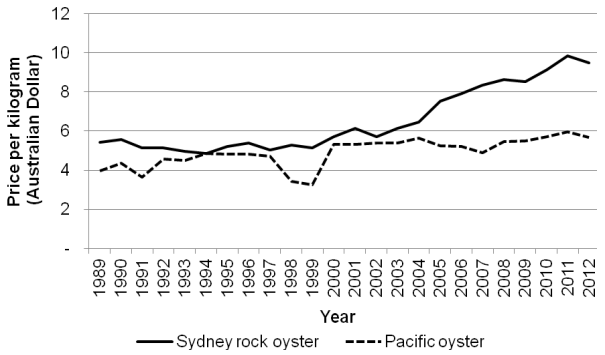

Fig. 5. Evolution of farm gate prices for edible oysters in Australia. Source: ABARE (1991; 1993–1997; 1999–2009), ABARE-BRS (2010), ABARES (2001–2013).

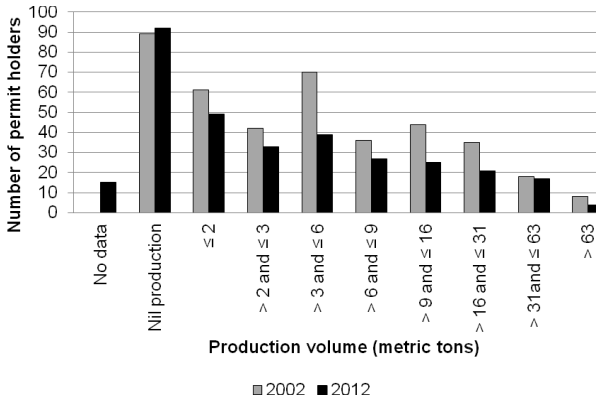

Fig. 6. Oyster aquaculture permit holders and scale of production in NSW. Source: NSW DPI (2003; 2013).

3.6 Consumer preferences, supply chain and marketing

2012) (Fig. 3). The major SRO producing estuaries are currently Wallis Lake, Port Stephens and Clyde River (Fig. 1).

The market for SROs remained almost exclusively domestic throughout the industry's development. Less than 1% of SRO is currently sold to overseas markets (NSW DPI 2013).

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 holders in NSW declined from 406 in 2002 to 322 in 2012 (Fig. 6). The distribution of the production scale within the industry has broadly remained unchanged over the period 2002–2012 (Fig. 6) (NSW DPI 2003; NSW DPI 2013). Figure 6 also illustrates that there is a high number for oyster farmers that produce no oysters or relatively small quantities of oysters per annum (less than 3 metric tons).

With a total production value of 28.8 million Australian dollars in 2012 (ABARES 2013) the SRO industry contributes less than 1% to Australia's total seafood production value which is dominated by prawn, rocklobster and salmonids production (ABARES 2013). However, in NSW this traditional industry remains the largest commercial fishing industry (ABARES 2013).

The SRO is a gourmet shellfish that is mostly consumed during summer which ranges from October to March. There is empirical evidence that oyster consumers in Australia prefer SROs over Pacific oysters (Mueller Loose et al. 2013). However, research on consumer preferences for edible oysters in Australia also found that species type is of low importance for consumers compared to other product attributes such as price and preparation format (e.g., opened and unopened oysters) and region of origin. The consumer preference ranking of the product price over species type may explain why demand for oysters has shifted towards the Pacific oyster in recent years (Schrobback et al. 2014a).

The supply chain and value chain of SROs has been described by Cominski (2009) and Hobday et al. (2014). Typical SRO supply chain components include production, processing, wholesale, retail, export and consumers (Hobday et al. 2014). Unfortunately, there is no information available about the proportion of oysters directly sold by SRO framers to different supply chain components (e.g., wholesale, retail). However, Cominski (2009) found that about 85% of oysters traded in Australia (which includes Pacific oysters) are distributed directly from producers to wholesalers. Only 12% of oysters produced in Australia are directly shipped from producers to

retailers, 2% are directly exported and 2% are sold directly to consumers (Cominski 2009).

There is also evidence that SRO farmers are mostly price takers as growers often don't have the access to information about the market, final consumers and the production capacity to influence the 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 final price of the SRO. Thus, farmers mostly receive the residual of the market price less marketing charges, packaging, and distribution prices (Cominski 2009). 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. This finding is also supported by Kow et al. (2008) who pointed out that the lack of branding and market development may have impeded oyster industry growth in the past. The available studies into consumer preferences for oysters in Australia suggest that product differentiation by price, preparation format, region of origin and species may potentially be beneficial to increase consumer demand for SROs (Liu et al. 2006; Kow et al. 2008; Mueller Loose et al. 2013).

3.7 Socio-economic profile

In 2001, the NSW oyster industry provided employment for about 1600 people and it was estimated that every direct job in the industry creates up to three indirect jobs (White 2001). It is likely that this estimate has decreased significantly with the decrease in SRO production volume and the number of oyster aquaculture permit holders (Fig. 6) over the past decade.

There are currently 322 oyster aquaculture permit holders in NSW (NSW DPI 2013) and 53 in Queensland (Wingfield and Heidenreich 2013). While there is no longitudinal survey data available about the socio-economic profiles of the SRO industry, a recent study examined the current socio-economic characteristics of the industry. The findings from this study suggested that the median age of oyster farmers in 2012 was 56 years and thus significantly higher to other Australian population and industry cohorts (e.g., Australian agricultural farmers had a median age of 53, Schrobback et al. 2014b). Unfortunately, there is no socio-economic information available for the Pacific oyster industry in Australia or other aquaculture of fisheries industries in Australia that allows a comparison.

Schrobback et al. (2014b) also found that the majority of SRO oyster farmers are Australian born and the first generation of oyster farmers within their families. A large proportion of current SRO growers have entered the industry in pre-retirement age and only a relatively low proportion of the oyster grower's household income is derived from oyster farming. Yet, there is evidence that oyster farmers have obtained a relatively high educational level compared to other Australian population cohorts. The results from Schrobback et al. (2014b) suggested that SRO farming is mostly undertaken as a part-time activity. The relatively low number of young farmers present in the SRO industry raises the question about industry entry barriers (e.g., opportunity coast, lack of access to capital).

Schrobback et al. (2014b) concluded their study by arguing that the socio-economic characteristics of the SRO industry have likely affected the economic performance of the industry in recent years. Schrobback et al. (in press) provided further support for that conclusion by showing empirically that the demographic characteristics of SRO farmers affected producer efficiency in parts of the industry.

3.8 Industry management

The current management of the SRO industry is a government responsibility, which is a classical management form found in many fisheries and aquaculture industries worldwide. Due to the juridical separation of the States in Australia, the SRO industry in NSW and Queensland is managed by two different government institutions, which are the NSW DPI and the Queensland Department of Agriculture, Fisheries and Forestry.

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 management responsibilities include, for example, the assessment of aquaculture areas, monitoring and enforcement of habitat protection and compliance as well as development of policies, standards and guidelines (efficiency reason). Other tasks 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].

During the 2000s, the SRO industry in NSW and Queensland both developed strategic management plans, that are the NSW Oyster Industry Sustainable Aquaculture Strategy (OISAS) and the Oyster Industry Management Plan for Moreton Bay Marine Park (NSW DPI 2006; QLD DPI 2008). Both plans set out best practice guidelines for the operation of oyster lease areas and focus on the long-term environmental

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

sustainability of oyster farming. Socio-economic dimensions of SRO cultivation (e.g., human capital investment) are not included in these strategic management plans.

4 Discussion

The early commercial development stage of the SRO industry was marked by the depletion of natural oyster stocks and resulted in early regulation of commercial oyster gathering. The cultivation of SROs was affected be a range of diseases over time to which the industry responded with innovations in production methods (e.g., stick cultivation and single-seed cultivation). Diseases and environmental pressure were the major reasons why the industry developed from a wild fishery into an aquaculture industry that is now partly reliant on hatchery spat. Coastal development and associated water quality impairments have negatively affected the SRO in the more recent history and so did the emerging Pacific oyster industry in Australia. Despite the continuous innovations in production techniques such as selective breeding, the production output of the SRO industry has continuously declined since the late 1970s and the future of the industry appears to be unclear.

Although the SRO industry shares some similarities in its development with the European oyster industry, it evolved slightly different to these industries.

For example, the native flat oyster (*Ostrea edulis*) industries in France and Britain experienced a similar extend in the depletion of natural stocks which resulted in regulation of the industry at around 1850 (Buestel et al. 2009; Humphreys et al. 2014). The oyster industries in France and Britain experienced a major crises around 1920 when sudden mortalities in the native flat oyster occurred which resulted in a significant loss in cultivated stocks. Further diseases and continued overexploitation of natural stocks severely affected the productive capacity of this native oyster species (Buestel et al. 2009; Humphreys et al. 2014). The industries in France and Britain responded to these crises by introducing the Pacific oyster in order to keep the oyster industry economically viable (Buestel et al. 2009; Humphreys et al. 2014). Today, the Pacific oyster dominates the oyster production in France and Britain. In fact, the Pacific oyster has been reported to have naturalised on the southern coast of Britain due to warming waters (Humphreys et al. 2014). Despite numerous efforts to assist the recovery of the native flat oyster industry in France, its production volume remains very low (Buestel et al. 2009).

The SRO industry has experienced a slightly different past than the European native oyster industries. Although diseases were the major reason for the prevailing decline in the productive capacity of the SRO industry, the magnitude of production shocks due to diseases appear to have been less severe compared to experiences in the European native oyster industries. Consequently, the decline in the productive capacity of the SRO industry may have been more gradual than in the European native oyster industries. In the case of Australia's native oyster industry, it has also been shown that the emerging Pacific oyster industry in Tasmania and South Australia had an adverse economic effect on the SRO industry (Schrobback et al. 2014a). Such an impact of the Pacific oyster industry in Europe on the native flat oyster industries has not been empirically proofed but is likely to exist.

A further reason that may explain why the SRO production is still commercially viable and has not yet been replaced by a major extend by more productive Pacific oysters is the relatively strict regulatory separation of SRO and diploid Pacific oyster production areas. Thus, the chosen invasive species management strategies and the concern about the effect that diploid Pacific oysters may have on the ecological future of SROs in NSW and Queensland industry also explain why the SRO industry in Australia experienced a slightly different history than the native flat oyster industry in Europe.

General issues that the SRO industry is currently facing and which it shares with the Pacific oyster industry in Australia and oyster industries worldwide include (Girard and Mariojouls 2003; Buestel et al. 2009; Girard and Pérez Agúndez 2014; Humphreys et al. 2014):

- Continuous management of diseases (reoccurring or new).
- Management of water quality impairments due to coastal development (e.g., pollution, water catchment management).
- Handling of unreliable spat recruitment.
- Ensuring shellfish food safety.
- Dealing with spatial competition from conservation, tourism, recreation and other commercial activities in estuaries.
- General lack in industry promotion (e.g., product marketing, branding).
- Labour intensive production methods.
- Shellfish diversification trend.
- Increasing need to monitor environmental change; and
- Lack of adaptation to climate change.

A continued exchange of experiences and cooperation between the oyster industries in the different counties will remain vital for the management of these issues nationally and internationally.

The review of the history and status of the SRO industry in this study showed that the economic viability of the SRO production is increasingly becoming under pressure. Hence, the industry management started to permit a gradual diversification of oyster aquaculture in NSW into triploid Pacific oyster production in selected estuaries. This industry management strategy is expected to increase returns to the industry, enhance oyster business resilience and to make more productive use of oyster aquaculture lease areas (NSW DPI 2014). Yet, statistics from a recent industry survey showed that oyster farmers remain much divided about this development (Schrobback et al. 2014b).

The management of the SRO industry is now facing the dilemma of either saving a "dying art" that has a historical and cultural value to the Australian society or providing oyster farmers an economic opportunity by expanding the triploid Pacific oyster industry. This is a predicament since despite the triploid Pacific oyster production may not be able to displace the SRO ecologically but it may do so economically (Schrobback et al. 2014a). 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 the expected positive effect on the revenue of farmers who choose to diversify their oyster production. Yet, at the same time the pressure on SRO prices and, thus, on the economic viability of the remaining SRO growers may increase due to an increasing supply of triploid Pacific oysters in NSW. As a consequence, SRO production may become commercially unviable in future. The question arises how resilient the native oyster stock would become if SRO cultivation would increasingly be replaced by triploid Pacific oysters.

A further concern provides the present structural issues which related to the demographic profile of the existing oyster industry. There is evidence that demographic characteristics of the industry have affected the productive efficiency of the SRO industry in the past and may likely do so in future (Schrobback et al. 2014b). These issues will not be eliminated by diversifying oyster aquaculture. The introduction of commercially more attractive oyster species may provide current oyster farmers an opportunity to maintain their economic viability in the short-run. However, without structural reforms (e.g., human capital investment, fostering innovation, better product marking) of the industry it is unlikely that the diversification of oyster aquaculture in NSW will contribute to an environmentally and commercially sustainable oyster aquaculture industry in NSW in the medium-run or long-run.

The industry is currently managed by government institutions. The alternative to the current management approach would the co-management approach which would require an increased participation of oyster farmers in industry management matters, e.g., development of management strategies, administrative tasks, and coordination of research efforts. Based on the knowledge about the socio-economic profile of the industry, a co-management approach would be inadequate. Therefore, a change in the industry's management approach would not be recommendable. Yet, a review of the SRO industry development strategies in consultation with oyster farmers and other industry stakeholders (e.g., research institutions) based on recent findings about the economic status of the industry in this study as well as in Schrobback et al. (2014a,b, in press) should be considered. Clearer and more focused industry development strategies may assist the future prospects of the SRO industry.

5 Conclusion

The aim of this study was to provide a review of the history and the status of Australia's native SRO industry and to discuss its potential future prospects.

The findings from this study suggested that there is a range of similarities in the development of the Australian SRO industry compared to the European native flat oyster industries. However, the SRO is slightly different compared to native oyster industries in Europe since it is still commercially viable but is increasingly becoming under environmental and economic pressure.

This study highlighted that major issues of the industry are the management of diseases, water quality impairments from coastal development, the economic competition from Australia's Pacific oyster industry and the current socio-economic profile of the industry.

Of particular concern for the SRO industry is the emergence of the Pacific oyster industry in Australia and the uptake of wild and triploid Pacific oysters in NSW. Given the economic and ecological dominance of Pacific oysters and the substitutability of both species in a market environment, the question arises as to whether the SRO is worth saving as a species and an industry. The "value" of the SRO industry largely derives from its economic contribution, particularly to rural communities in NSW. However, the SRO also has an important ecological role as a native Australian species. Furthermore, the industry has a vital position in the historic development of Australian aquaculture and therefore has a considerable cultural and heritage value to the Australian society. Thus, it is impossible to ground the choice of the preservation of a "dying art" industry on pure economic aspects (Peacock 1991). The future of the SRO industry will therefore even more depend on management decisions that include the societal value of the species and the industry. It can be concluded that culturing SROs "requires an intelligent industry in order to turn natural advantage to the best account" (NSW Royal Commission on Oyster Culture 1877).

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