Food and Agriculture Organization of the United Nations

Proactive approach proved key to survival for the **Australian Pacific oyster** industry

GENETICS
IN AQUACULTURE
A CASE STUDY

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Contents

1. Introduction

The foresight of Australia's Pacific oyster growers in establishing their own selective breeding programme proved crucial to saving the industry when increasingly widespread outbreaks of a deadly Ostreid herpesvirus threatened its future.

2. Background

The Pacific cupped oyster *Magallana gigas* (previously classified as *Crassostrea gigas* and known as the Pacific oyster in Australia) is one of the most widely farmed oysters in the world. It is grown in 33 countries, and on every continent except Antarctica. In 2018, global production totalled 643 549 tonnes valued at USD 1 365 billion. Major producers included the Republic of Korea (303 200 tonnes), Japan (176 000 tonnes), France (84 200 tonnes) and the United States of America (23 797 tonnes) (FAO, 2020). Australia produced up to 10 000 tonnes (See Figure 2) and New Zealand produced 3 000 tonnes (FAO, 2020).

However, the industry globally is under increasing threat from an Ostreid herpesvirus (OsHV -1) first identified in France in the 1990s. Initially affecting juvenile oysters, since 2008 the microvariant OsHV-1 µvar has caused mass mortalities in both juvenile and adult oysters throughout Europe and elsewhere. The disease resulting from OsHV-1 infection is widely referred to as Pacific oyster mortality syndrome or POMS. Infection spreads rapidly and entire juvenile oyster populations are killed; mortalities of 90 percent or more may occur in farmed adult populations in just a few days.

POMS spread quickly throughout Europe, from France in 2008 to the United Kingdom of Great Britain and Northern Ireland, Ireland and Spain in 2009, and to New Zealand and Australia in 2010. It has since established itself as a global threat. By 2020, infections had also been reported in Brazil, China, Japan, Republic of Korea, Mexico, Morocco, Tahiti and the United States of America (Hassou *et al.*, 2020).

Once POMS has infected a waterway, disease outbreaks recur when environmental conditions combine to support its growth. These conditions include warm water temperatures, which are expected to be an increasing issue for aquaculture as global temperatures rise. POMS is predominantly a summer seasonal disease for the temperate Pacific oyster species with major outbreaks occurring in Australia when temperatures exceed 21 °C, although threshold temperatures are lower in other countries.

The economic and social impacts of these mass mortalities have been devastating for growers and their communities. Oyster growing businesses are often sited in small rural communities where they are an important source of employment and economic activity. POMS outbreaks have led to business closures and job losses as a result of lost production. Significant numbers of growers have left the industry as a result. (Radio New Zealand, 2011; FRDC, 2016)

In France, national production almost halved, declining from 110 800 tonnes in 2007 to a low of 64 200 tonnes in 2015. Ten years after its first major POMS outbreak, French production remained well below pre-POMS levels, totalling 84 200 tonnes in 2018 (FAO, 2020). Outbreaks continue to kill about 35 percent of natural and cultivated spat and juvenile oysters in France (Petton *et al.*, 2021).

Australia's Pacific oyster industry is about a tenth of the size of the French industry. It involves hundreds of small businesses and total production is variable, reaching up to 11 200 tonnes per year (Figure 2). In 2015/16, the year before POMS first had a significant impact on national production, the sector produced 8 086 tonnes of Pacific oysters valued at USD 42 million, making it Australia's third most valuable aquaculture sector. (ABARES, 2020; New South Wales Department of Primary Industries, 2006-2020).

Pacific oysters are grown in three states. South Australia generally accounts for 55-60 percent of production, while 36-40 percent comes from Tasmania and 3-8 percent from New South Wales (NSW). Sydney rock oysters (*Saccostrea glomerata*), widely produced in New South Wales, and pearl oysters (*Pinctada spp.*) produced primarily in Western Australia, are not susceptible to POMS.

The Pacific oyster industry has been based almost exclusively on hatchery reared spat since the establishment of hatchery technologies in Tasmania in the 1980s. A decade later, the Australian Government funded research to develop a selective breeding programme to accelerate oyster growth rates, including the production of sterile triploid oysters. This work was supported by industry bodies and research agencies, including the Fisheries Research and Development Corporation (FRDC), a co-funded partnership between the Australian Government and the fishing and aquaculture industries. The initial research work was conducted by Australia's national science agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the University of Tasmania.

As a spin-off of this research, Pacific oyster growers established an industry-owned breeding company, Australian Seafood Industries Pty Ltd (ASI), in 2004 to produce their own 'thoroughbred oysters' with superior qualities for premium consumer markets. This allowed the many small growers in the industry to pool their resources effectively to invest in a genetics programme that they could not have afforded individually. The official shareholders in ASI are industry associations, namely the South Australia Oyster Growers Association (SAOGA), the South Australian Oyster Research Council (SAORC) and Oysters Tasmania.

ASI is based in Tasmania, sharing hatchery facilities at the University of Tasmania's Institute for Marine and Antarctic Studies (IMAS). Its programme initially targeted a combination of market traits, including survival, growth rate, shell shape and hardness, and meat quality. Previous breeding programmes that solely targeted faster growth rates had produced oysters with unmarketable shell shapes. By 2010, ASI had produced 50 families in total for use in replicated performance trials in New South Wales, Tasmania and South Australia.

The genetic material ASI produced was available to all industry participants through a royalty system that helped to fund the breeding programme. The industry-wide focus also allowed the company to secure a series of government research grants to supplement the small royalty income from the use of its advanced broodstock.

Ongoing collaborations with government research agencies in each state were important to ASI. These collaborations included the New South Wales Department of Primary Industries (NSW DPI), the South Australian Research and Development Institute (SARDI), and IMAS. Oyster growers actively assisted with the research programme, hosting trials and helping with logistics. CSIRO is an ongoing partner in the research, helping with trial design, providing data analytics services and generating estimated breeding values (EBVs) on which selection and production decisions are based. The relationships with these organizations proved crucial in helping ASI, and the industry as a whole, to respond quickly when POMS first struck in Australia.

The first POMS outbreak occurred in the Georges River, near Sydney, in November 2010. The two Pacific oyster growers in the area reported losing up to 100 percent of oysters of three to six months of age and up to 60 percent of older oysters. A second wave of infection in 2013 reached four other rivers and estuaries in the Sydney region and affected many more growers; these included those in the highly productive Hawkesbury River, where losses were estimated to be worth more than USD 2 million. As a result of these outbreaks some Pacific oyster growers left the industry and others re-focused their production to the native Sydney rock oyster. The latter has a long history of farming in New South Wales but is slower growing and has its own disease challenges.

In late January and February 2016, the industry was shocked when the disease jumped to another state, with major POMS outbreaks in five important growing areas in southern Tasmania (Figure 1). Growers suffered up to 95 percent mortality on infected farms. Over the course of a few weeks POMS killed more than five million dozen oysters valued at over USD 8 million; more than 80 jobs were lost (FRDC, 2016). The University of Tasmania estimated the economic losses over 2016 and 2017 at USD 38 million (University of Tasmania, 2017).

Tasmanian hatcheries produced 90 percent of the spat for the industry nationally and most hatcheries were located in POMS-affected areas. Biosecurity measures to stop the spread of the disease meant these hatcheries were prevented from selling spat into POMS-free regions, including South Australia. These hatcheries immediately lost more than half of their income. The restrictions on spat sales from Tasmania, in turn, created a production crisis in South Australia which had only two small hatcheries. Despite having no outbreaks of POMS, the effect of the spat supply problems in South Australia meant that the broader impacts of the disease have been longer lasting and more significant than those of direct POMS infection in Tasmania.

3. The industry response

3.1 The technical approach within the ASI breeding programme

Australian industry leaders had been on alert since 2008 when the mass oyster mortalities were first reported in France but were disturbed by how quickly POMS arrived in Australia. Their response to the initial outbreak in 2010 was to refocus the efforts of the ASI industry breeding programme from production and market-related traits, such as growth rate and uniform shell shape, to breeding for POMS resistance.

Within weeks of the first POMS outbreak in New South Wales, ASI established a trial of its adult oysters in infected waters to assess the disease resistance of its families. PCR tests of the ASI oysters identified large differences in the way individual animals had accumulated the virus within their tissues. Some individuals demonstrated high viral loads and others none. ASI estimates 5 percent of the adult oyster population has natural resistance to POMS and the first exposure of its families to POMS allowed the company to identify which of its pedigree lines demonstrated some resistance (M. Cunningham, personal communication, 2021).

This provided enough evidence for ASI to pursue selective breeding for POMS resistance as a proactive industry-preparedness strategy. Working with state and national research partners, ASI was able to run trials in which all their family lines were deliberately exposed to POMS outbreaks in affected waterways in New South Wales.

Industry and research partners helped to develop selection indices which prioritised POMS-resistance in calculating estimated breeding values (EBVs). The EBVs also included some of the previous selection traits related to culture performance and marketability to ensure that other quality gains already achieved were maintained as POMS resistance was improved. This strategy was also critical to control inbreeding.

In 2011, ASI secured Australian Government funding through the Seafood Cooperative Research Centre (CRC) for a three-year project to confirm heritability of resistance to POMS and establish realistic breeding targets for resistance. This funding also helped to expand the number of families created each year from 50 to 80, thus increasing the overall response to selection. It also allowed for targeted challenge tests in a biosecure facility as well as exposure trials in the field. Partners in this research with ASI included the CSIRO and NSW DPI.

Biosecurity restrictions following the outbreak of POMS in New South Wales disrupted the interstate movement of ASI broodstock. ASI and its breeding families were based in Tasmania while the research and the challenge tests were being performed in New South Wales. Oysters from ASI's families in Tasmania were sent to estuaries in New South Wales for natural exposure challenges. Small numbers were also sent to a biosecure laboratory in New South Wales for experimental challenges. However, oysters that survived either natural or laboratory challenges could not be returned to Tasmania.

This meant that in the first few years of the POMS-resistance breeding programme ASI could only breed from the Tasmanian-based relatives of the oysters that survived rather than directly from survivors. Direct breeding would have provided a more reliable transfer of resistance between generations and a stronger selection intensity.

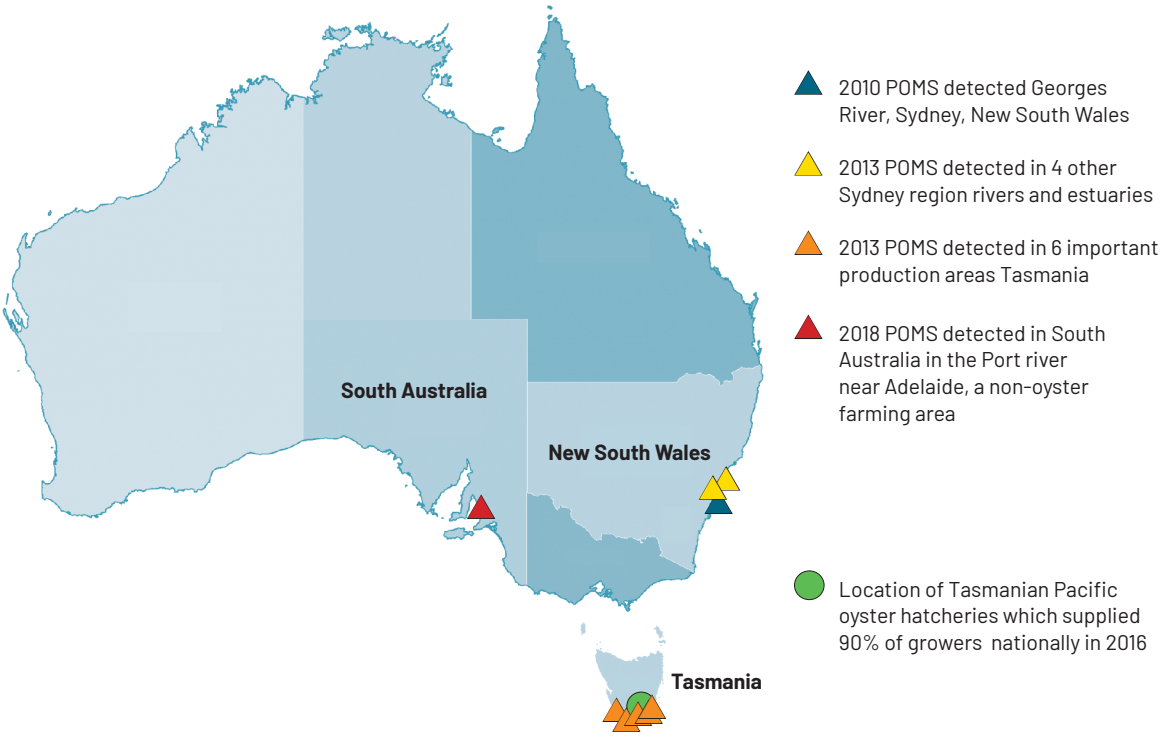
In 2013, the second major outbreak of POMS in New South Wales further galvanised support for the ASI breeding programme and increased the urgency of breeding for resistance. Industry acknowledged it would be "when", not "if" POMS would spread to major Pacific oyster growing areas in Tasmania and South Australia (FRDC, 2013). ASI trials were already clearly showing the heritability of resistance. Researchers noted that few (if any) Pacific oyster traits responded as well to selection as did POMS-resistance, enabling robust predictions of genetic gains. These gains accumulated in each annual cycle of ASI breeding and increased survival of one-year-old oysters by at least 10 percent per year (Kube *et al.*, 2018).

When the project funded by the Seafood CRC ended in 2014, ASI had confirmed increasing levels of resistance among its families and had a clear plan for what could be achieved and how to achieve it. It confidently predicted 70 percent survival of one-year-old oysters by 2018 in the event of a POMS outbreak.

In order to continue funding the expanded programme and develop long-term strategies that relied less on government grants, ASI approached the state industry associations and their members with a proposal for a POMS resistance breeding levy. This was calculated at around- USD 2 per 1 000 spat sold by all hatcheries, whether or not the hatchery had used ASI broodstock to produce that spat. This proposal was based on the principle that the development of POMS-resistant oysters would benefit the industry as a whole, even if individual growers opted out of using the products of the breeding programme.

Anticipating that the levy could lead to an equivalent increase in the price of spat by all hatcheries, ASI also applied to the Australian Competition and Consumer Commission for an exemption from what might be seen as price-fixing behaviour. A 10-year exemption was granted, allowing the levy to be struck. It is a tribute to the industry leaders of the day that they were able to convince the majority of oyster growers in all three states to support the levy.

Figure 1. Timeline showing the spread of Pacific oyster mortality syndrome (POMS) in Australia



3.2 The scope and scale of application of the ASI breeding programme

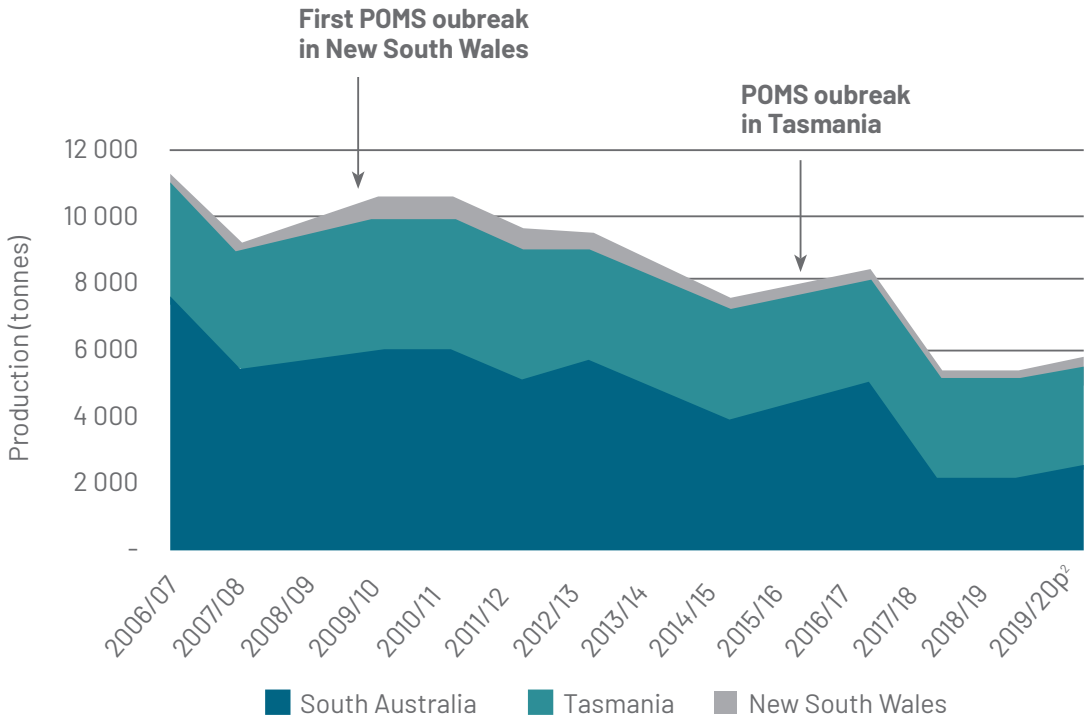
In early 2016, POMS struck in Tasmania. Here the outbreak immediately validated the ASI breeding programme and showed that research undertaken in New South Wales was directly transferrable to the Tasmanian broodstock. ASI's selected families were being hosted and on-grown in commercial farms in affected Tasmanian areas when the POMS outbreak occurred. While growers experienced up to 95 percent mortality with their own oysters, the best ASI families in the water at the time suffered only 20 percent to 40 percent mortality among one-year-old oysters.

In presentations at various grower workshops held in the wake of the POMS outbreak, ASI was able to demonstrate the progress of its breeding programme. This provided a clear path towards solving the disease challenge and ensuring the long-term survival of the industry, and was crucial in giving growers the confidence to re-invest in spat and continue farming. In Tasmania all growers initially remained in the industry, despite the POMS situation. This had not been the case following the early outbreaks of POMS in New South Wales or in New Zealand from 2010 onwards. The Tasmanian government also provided significant support to growers, through license fee waivers and low interest loans.

The arrival of POMS in Tasmania allowed ASI to renegotiate arrangements with all Pacific oyster hatcheries. This entailed establishing a service agreement with payments based on the number of spat sold; this replaced the more contentious levy on individual growers. Although this action streamlined ASI's source of income, much of the potential income for ASI simultaneously disappeared due to the huge drop in spat sales in the aftermath of the outbreak.

While only one hatchery suffered major losses because of POMS, most were located in infected regions. The biosecurity protocols activated in the wake of the Tasmanian outbreak prevented all Tasmanian hatcheries from selling spat into uninfected areas in other parts of the state or to New South Wales. They also could not sell any spat to South Australia, which remained disease free. The market for their spat more than halved, significantly reducing their own income, as well as ASI's. The Australian Government stepped in with emergency funding to underwrite ASI's operating costs for one year, recognizing the value of its programme in helping the industry to recover from this crisis.

Figure 2. Australian Pacific oyster production 2006/07 to 2019/20



Source: ABARES, 2020.[1] Australian Fisheries and Aquaculture Statistics 2020. https://www.awe.gov.au/abares/research-topics/fisheries/fisheries-data#australian-fisheries-andaquaculture-statistics-2020

Notes:

1 ABARES calculates production for Tasmania and South Australia as one dozen Pacific oysters equal to one kilogram. ABARES data for New South Wales does not distinguish between different oyster species grown in the state. New South Wales production has been added from annual aquaculture production reports prepared by the New South Wales Department of Primary Industries, 2006-2020.

2 2019-20 results are provisional.

The rapid deployment of POMS-resistant oyster families from the ASI breeding programme allowed the industry in Tasmania to recover quickly.

Prior to the outbreak of POMS in Tasmania, uptake of the ASI strain had remained < 25 percent of total national spat sales. By 2017, after the Tasmanian POMS outbreak, ASI broodstock provided the basis for 100 percent of commercial spat produced in Tasmania. The ASI oyster had an expected survival of 80 percent for one-year-old oysters in a POMS disease event, exceeding ASI's performance targets (Kube *et al.*, 2018). Spat produced from this broodstock were subsequently sold to growers in Tasmania and some parts of New South Wales. Following the Tasmanian outbreak ASI was able to expose its families to infection in local waters and to breed directly from survivors, accelerating progress. By 2020 it reported 100 percent resistance in one-year-old oysters.

As sales of spat resumed, ASI's income stream from the service agreement with hatcheries recovered. Improved biosecurity protocols allowed hatcheries to sell to uninfected areas of Tasmania and New South Wales, and those areas have remained free of POMS, as of 2021. However, sales of Tasmanian spat to the major market in South Australia have remained on hold since 2016. In 2018, POMS was detected in feral Pacific oysters in the Port River near Adelaide in South Australia, but as of 2021 it has not been found in the state's growing regions.

South Australia was particularly hard hit by the restrictions on spat transfers; this crippled the industry there, although only a few growers opted to leave the industry. The state has since established its own hatcheries, which are also party to the service agreement with ASI. However, production in South Australia continues to lag behind pre-POMS levels even five years after the Tasmanian outbreak, despite no direct outbreak of disease there. In contrast, Tasmanian growers were operating at pre-POMS production levels within three years (Figure 2).

From 2016 to 2019 a further three-year research programme, known as the Future Oysters Cooperative Research Centre Project (CRC-P), provided additional funds for ASI breeding work. This allowed ASI to focus on improving POMS-resistance in the younger spat which were not as resistant as older oysters. While ASI's one-year-old oysters neared 100 percent resistance, only about 30 percent resistance was achieved in three-month old (~2 mm) spat. In the most recent Tasmanian POMS outbreak of note (in 2019) the best surviving three-month-old families showed 60 percent resistance. The ASI target is 70 percent resistance in three-month-old spat by 2022.

ASI also expanded its presence in South Australia in 2016, establishing a breeding hub in partnership with SARDI in Adelaide. It created new families in South Australia, breeding from oysters involved in its trials that were on-going in the state prior to the Tasmanian POMS outbreak. These oysters already had improved genetic resistance to POMS. However, ASI had no way to challenge its new families with POMS in South Australia in order to continue building resistance. This South Australian POMS resistance breeding programme, having no access to the POMS-resistant broodstock in Tasmania because of biosecurity restrictions, began to founder.

However, growers in South Australia saw this as an opportunity to address a more immediate local need: improved resilience of spat and juvenile oysters to local environmental conditions. Undetermined environmental triggers, rather than disease, had resulted in periodic mass mortalities of pre-adult oysters, which had contributed to fluctuations in the state's production since its industry was founded.

In 2020, ASI received additional funding through the FRDC to support its South Australian breeding programme. Also, in March 2021, the Tasmanian and South Australian governments approved a strict biosecure translocation protocol that enabled ASI to transfer small numbers of POMS-resistant Tasmanian broodstock to its breeding hub in South Australia. This will provide an emergency back-up for breeding in the event of a POMS outbreak in the state. Over the next few years, ASI will merge the Tasmanian POMS resistance traits into the new South Australian families.

In 2021, ASI's families underpinned about 20 percent of Pacific oyster production in South Australia and 90 percent in Tasmania with some hatcheries trialling their own resistant broodstock. In New South Wales 100 percent of hatchery spat used is produced using ASI genetics; however, wild-caught spat is also used by some growers in the state.

ASI is embarking on new research into genomic selection for oyster breeding. This will advance traditional selection based on phenotypic traits adding selection for some traits based on identifying markers in the genomic sequence of oysters that are associated with the desired traits. This research will be funded jointly by the oyster industry and FRDC and is expected to get underway in 2022.

4. The New Zealand response

The arrival of POMS in New Zealand in 2010 more than halved production there, with highly variable impacts from one location to another. More than 95 percent of oyster production is based on New Zealand's North Island, which was particularly hard hit; growers on the South Island suffered little impact. National production dropped from about 3 000 tonnes in years prior to POMS to 1 200 tonnes in 2012.

By 2018 production had recovered to almost 2 000 tonnes (FAO, 2020). New Zealand's Pacific oyster industry is dominated by production systems using wild caught spat raised on sticks but there has been a gradual increase in the use of hatchery-bred spat over the past 15 years.

The Cawthron Institute, which is New Zealand's largest independent science agency for primary industries and the environment (established by a private endowment), is based in Nelson on the South Island. Since 2001 it has been partnering with the Pacific oyster industry to develop hatchery technologies and a selective breeding programme. By 2010, hatchery produced spat was responsible for about 25 percent of national production.

Similar to the situation in Australia, the breeding programme initially focused on traits such as growth rate and improved oyster quality, alongside the development of triploid oysters for year-round production. Following the POMS outbreaks in 2010, the Cawthron Institute quickly shifted its breeding priorities toward POMS resistance.

The first trials for resistance in 2011 used families created from both the selected breeding programme and wild harvested oysters that had survived the previous POMS outbreak. Within a month of 10 mm spat being put out on marine farm leases another POMS outbreak struck. Mortality of the trial families varied from 50 percent to 95 percent, providing a clear signal to researchers that breeding for resistance would be possible.

The Cawthron Institute typically spawns oyster families biennially. Effective biosecurity measures (such as ultraviolet treatment of seawater in the hatchery, ageing of nursery and broodstock seawater, and PCR testing of spat prior to leaving the hatchery) and the fact that most farm areas were already POMS-affected meant Cawthron was able to breed directly from the survivors of POMS-challenged oyster families. Leveraging government and industry support for its programme, the Cawthron Institute was able to achieve 80 percent survival for spat within six years.

By 2021, the Cawthron breeding programme provided the basis for 40 percent of New Zealand's production. This increase was driven by the country's largest oyster producer, Moana New Zealand, which holds 45 percent of leases and is pursuing a hatchery-based production strategy (Aquaculture New Zealand, 2015). Moana is the largest Māori-owned fishing and aquaculture company in the country and has been a long-time partner in Cawthron's breeding programme.

In 2021 Moana established its own hatchery co-located with the Cawthron Institute in Nelson and now operates its own breeding programme, using the POMS-resistant oyster families from Cawthron. The Cawthron Institute will continue to provide small-scale spat requirements for other industry participants.

5. Key lessons

Researchers and industry organizations in both Australia and New Zealand claim that having established breeding programmes in place when POMS arrived was critical to the success of their resistance breeding efforts. Many years of work had already gone into developing the infrastructure, breeding protocols and human resource capacity needed for a successful genetic improvement programme before the disease hit the industry.

While neither country has had total industry uptake of advanced genetics, the breeding programmes themselves allowed the programme operators to respond rapidly, pivoting their priorities towards POMS resistance.

Strong public-private partnerships are a common feature of the breeding programmes in Australia and New Zealand although the nature and structure of these partnerships differs. Both countries use collaborations to establish world-class breeding programmes that individual growers would not have been able to fund privately. Growers who otherwise compete strongly in the market, agreed to work together to achieve this.

In Australia, industry foresight and leadership led member organizations to establish their own breeding company, which attracted significant government funding in its early years. This strong direction encouraged industry uptake of improved strains. In New Zealand, the Cawthron Institute provided the initiative for this work, in response to growing interest in hatchery technology from the local industry. Breeding programmes in both countries are now able to operate

independently from government funding to respond to industry needs. However, the strong relationships established over the years ensure that the breeding programmes are still able to receive periodic funding for new research and development initiatives.

The right business and funding model is important in allowing an industry programme to operate independently of government. Industry buy-in is critical to this, whether it is through the purchase of products, levies or other service agreement mechanisms. Strong industry leadership is needed to establish these arrangements. The transition from public to private funding, particularly while maintaining industry-wide access to the improved genetics, proved challenging in Australia. Business planning for this transition when establishing a breeding programme could improve this process.

Open and ongoing communication allowed both ASI and the Cawthron Institute to demonstrate the value of their breeding programmes to growers. This in turn provided industry members with confidence that a solution to POMS was available, allowing them to remain in the industry, to invest in the future, and even to expand, as Moana did in New Zealand.

In Australia, the need for robust and scientifically based biosecurity policies and practices emerged as an issue for hatcheries that had been producing POMS-free spat since 2016. These biosecurity restrictions limited the ability of growers in South Australia, and to a lesser extent in New South Wales, to take advantage of the improved strain when available.

Participants in the Australia programme have also noted that government staff and research agencies had the operational flexibility to help ASI to adapt its breeding programme to changing conditions. This was facilitated by the longstanding collaborations between ASI and these organizations, which provided ongoing access to valuable scientific and technical expertise. This framework, supportive rather than bureaucratic, is seen as important to the success of the programme and the survival of the Pacific oyster industry in Australia.

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The global Pacific oyster aquaculture sector is plagued by a disease caused by the Ostreid herpesvirus, known in some countries as Pacific oyster mortality syndrome (POMS). POMS first arrived in Australasia in 2010 and caused massive mortalities, especially of young oysters, sometimes bringing about close to 100 percent mortality. At that time the Pacific oyster industries in Australia and New Zealand had already initiated genetic breeding programmes for commercially important growth related traits. As POMS arrived in the region and started to spread throughout the two countries, these breeding programmes were able to pivot to breeding for POMS resistance, which turned out to be a highly heritable trait and responded very well to selection such that by 2018, selected oysters had average survival rates of around 80 percent during POMS outbreaks.

This case study traces the development of oyster breeding programmes in Australia and New Zealand and describes how the industry sectors were able to respond quickly to the new and immediate threat of POMS and how the existence of on-going breeding programmes, supported by both public and private sector, was critical to saving the industry from being completely decimated by POMS and how the breeding programmes enabled relatively rapid recovering from POMS related losses. The study identifies the critical role of public private partnership in the success of the breeding programmes and identifies some of the funding mechanisms that ensured on-going success of these programmes.

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