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Sydney Rock Oyster Breeding Program technical review

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Prepared for Oysters Australia Pty Ltd and Fisheries Research and Development Corporation

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Glossary

Term	Definition
AGBU	Animal Genetics and Breeding Unit
ARAC	Aquaculture Research Advisory Committee
ASI	Australian Seafood Industries Pty Ltd
ASReml	Standard quantitative genetics analysis software for estimation of EBVs and genetic parameters
BLUP	Best linear unbiased prediction
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUDLS	Cawthron Ultra Density Larval System
Deployment	In the context of shellfish breeding, the process of using the top breeding program families to produce large quantities of genetically improved hatchery spat that are commercially farmed
Estimated breeding value	EBV; a prediction of the genetic worth of an individual or family for breeding based on its own performance and / or that of its relatives
Family	A group of (genetically similar) siblings formed from the mating of one female with one male
FRDC	Fisheries Research and Development Corporation
Genetic correlation	A measure of the shared genetic control between traits – the effect on trait A of selecting for trait B
Genetic gain	The genetic progress made through selection and breeding for a specific trait or breeding objective
Genotype	The genetic makeup of an individual as determined by its genes
Genotype-by-environment interaction	G×E; the consistency with which genetic effects are expressed across different environments or growing systems

Term	Definition
Genomic relationship matrix	GRM; describes the relationships between all individuals in a population based on genetic similarity (determined by genotyping) as opposed to assumed similarity based on pedigree
Genomic selection	The use of genome-wide genetic markers to calculate genomic EBVs (GEBVS) based on actual genetic similarity rather than inferred similarity as is the case with pedigree based EBVs
Heritability	The proportion of observable phenotypic variation that is genetically determined, ranging from 0 (no genetic control) to 1 (full genetic control). Heritability for any given trait can vary between environments, e.g. genetic differences in growth rate are less likely to be expressed where food supply is severely limited
MOU	Memorandum of understanding
NSW DPIRD	New South Wales Department of Primary Industries and Regional Development
Phenotype	The observable characteristics and performance of an individual resulting from the interaction of its genotype and environment
Single nucleotide probe	SNP; a type of genetic variant used in genotyping
SOCo	Select Oyster Company
SRO	Sydney Rock oyster
SROBPAG	Sydney Rock Oyster Breeding Program Advisory Group
SROBPRG	Sydney Rock Oyster Breeding Program Reference Group
SROBPTC	Sydney Rock Oyster Breeding Program Technical Committee
QX	'Queensland Unknown' disease, caused by *Marteilia sydneyi*, a parasite of the Sydney rock oyster
UNE	University of New England

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Executive summary

The Sydney Rock Oyster (SRO) Breeding Program is a strategically important platform for maintaining and expanding the resilience, productivity and sustainability of the oyster industry in New South Wales, Australia.

Significant gains in processes and outcomes have been made since the program's inception, working with a difficult species in a complex environment. However, there is a sense now that the program is plateauing, weary from battling the challenges of nature, and tired from trying to solve its own internal issues.

While strong progress has been made in establishing a family-based selective breeding program and demonstrating genetic gain for key traits, critical structural, operational and stakeholder alignment issues continue to limit the program's impact. There is a need to reinvigorate the program in order to focus on sustained progress and realise its potential.

The status quo is not a sustainable option. Without decisive transformation, the breeding program faces a slow erosion of trust, capability and relevance. State investment will likely diminish. Scientific and operational capacity may be lost or further constrained. Industry confidence will continue to wane, and with it, the sector (and state) risks losing one of its most powerful tools for growth, resilience and future readiness

This review found that the program needs improved co-ownership models and a realignment of roles, as well as more robust deployment models and genetic performance feedback systems. Next-generation hatchery systems have the potential to efficiently improve the rate of genetic gain and eliminate several critical deployment issues. A shift in focus from disease resistance to broader resilience, with a stronger commitment to responsiveness, traceability and co-investment, are required. The breeding program needs to re-envision itself as an integrated 'lab-to-farm' supply chain to deliver on its promise.

Plain English summary

The Sydney Rock Oyster (SRO) Breeding Program is an important tool to safeguard the future of the oyster industry and help realise its full potential. The program has already shown that breeding can produce oysters that grow faster and survive better under a disease challenge. However, our technical review found that the program is not yet delivering its full potential to SRO farmers.

With appropriate change, the program can become a powerful partnership that provides farmers with reliable and high-performing spat, builds industry resilience to new challenges, and supports growth and profitability.

How does breeding work?

In the lab, breeders select the 'best' oysters from previous generations or take new oysters from the wild. Pairs of male and female oysters are mated together to produce many families where all the oysters in a family are brothers or sisters.

Once the families have been reared through their challenging larval (swimming) phase, they are transferred as spat to farms where they grow under commercial conditions. The spat are measured and their survival is monitored, and the best-performing families are selected as the next breeding generation. The new and 'improved' generation is used as hatchery broodstock for commercial spat production.

What traits or attributes determine the best family? Breeders generally target traits that are economically valuable and heritable – more nature (genetic) than nurture (environment). For example, a trait like eye colour is heritable (and breedable). Traits may be genetically correlated and 'work together' like shell size and meat weight – if you breed for one, you get the other for 'free'. When traits are negatively correlated, like shell growth and meat condition, breeders have to be careful not to breed for one at the expense of the other.

Why the program matters

- Oyster farmers face tough conditions. QX disease, low-salinity events, pollution and climate change all threaten oyster production.
- Selective breeding works. The program has proven it can lift oyster growth and survival. There are long-term, year-on-year, cumulative benefits to productivity.
- Program benefits must meet the needs of farmers and be visible. Farmers can only receive value from the program if improved stock reliably reaches hatcheries and farms. Currently, industry engagement and an effective supply chain are lacking.

Key problems limiting the program

- Family production is unreliable. Too many families are lost in the hatchery, which makes it difficult to breed the best families. This limits the options for commercial supply and creates extra work.
- Objectives need refreshing. The old targets (70% QX survival, 30% faster growth, no loss of condition) don't reflect the needs of all the farmers in the different regions. Resilience across multiple challenges is becoming more relevant.
- Breeding program researchers are overburdened. The researchers face too much on-farm work, which stretches resources and misses an opportunity for industry engagement.
- Deployment is uneven. Not all farmers or hatcheries get access to improved stock when they need it. There is little traceability from broodstock to farm, so it's hard to know if spat are performing well because of their genetics or for other reasons.
- Governance is fragmented. The NSW DPIRD is seen as responsible for everything, leading to blame when things go wrong, stretched resources and limited buy-in from industry.

What needs to change

- Modernise family production. Evaluate improved hatchery systems (e.g. flow-through larval tanks) to lift reliability and ensure all families are available for deployment. This change will also free up resources.
- Refresh breeding goals. Move beyond simple resistance to embrace resilience – survival + growth + condition under real farm conditions. The program direction should be reviewed every year and the changes recorded.
- Shift the workload to industry. Farmers and hatcheries should take greater responsibility for running trials and managing broodstock, with NSW DPIRD providing training, data systems and oversight. NSW DPIRD can then focus on the science, and industry can experience family performance for themselves.
- Build a reliable deployment supply chain and create traceability. Ensure broodstock and spat are supplied in time and with a clear indication of genetic merit. A certification system would help end-users link genetic value to on-farm performance and establish their own value proposition.
- Build true partnership. Establish a co-leadership model between NSW DPIRD and industry (including hatcheries). Shared responsibility, transparency and co-investment are the foundation for long-term success.

The choice ahead

- If nothing changes, funding, capability and trust will erode, with the risk that industry loses a vital tool for securing its future.
- With transformation, the 'lab-to-farm' program will deliver reliable genetic gain, empower farmers and hatcheries, attract new investment and provide insurance against future shocks.

The message is clear: the breeding program must shift from being 'DPI's program' to being everyone's program. Shared ownership and responsibility are the only way to unlock its full potential and secure the future of the SRO industry.

1. Introduction

The New South Wales (NSW) Sydney rock oyster (SRO) industry has long operated under the shadow of environmental volatility and endemic disease pressures. QX disease (caused by *Marteilia sydneyi*) has been particularly disruptive, both economically and psychologically, shaping farm practice, site viability and confidence in long-term investment. Compounding this concern are increasing environmental stressors, which include more frequent and prolonged low-salinity events driven by climate change, bushfire-associated run-off, catchment pollution and infrastructure development. Together, these forces have created a production environment where even robust farm management cannot guarantee reliability.

The SRO Breeding Program was established in response to these challenges. Initially based on mass selection principles, it has evolved into a structured, family-based program enabling more precise control over genetic gain and trait improvement. The program's technical design, centred at the New South Wales Department of Primary Industries and Regional Development (NSW DPIRD) in Port Stephens, is broadly aligned with global best practice including use of full-sib families, deployment in QX challenge environments, and collection of growth and condition data to support best linear unbiased predictor (BLUP)-based EBVs.

Despite the program’s strong technical foundations and success in creating improved genetic lines, its full potential has been constrained by shifting requirements and various systemic challenges. Diseases such as QX and other resilience-related issues are not easily addressed by single-factor resistance strategies. Persistent fragmentation across the breeding-to-deployment value chain, coupled with environmental unpredictability and commercial pressures on hatcheries, have created a lag between genetic innovation and commercial impact. A lack of mechanisms for tracking the uptake and performance of improved spat in commercial settings has made the value proposition difficult to demonstrate. Ongoing resourcing constraints have been challenging, particularly in areas critical to delivery, communication and industry alignment. Ultimately, the program has struggled to consistently deliver and deploy genetic improvement at scale.

Alongside these challenges, the program is increasingly expected to be both the technical solution and the strategic enabler – supporting industry viability, adaptation and productivity. This places new pressure on the system to not only deliver genetic gain, but also ensure that this gain is relevant, communicated and deployed effectively. To do this, the program requires technical competence alongside structural coherence, strong industry engagement and governance models that support responsiveness, transparency and shared accountability.

Over the past two decades, these challenges have been the subject of multiple independent reviews. While each review has contributed valuable insights and often reaffirmed the technical strengths of the breeding program, they have also highlighted recurring structural and operational issues. Many recommendations – particularly those relating to governance, transparency, deployment pathways and clearer performance accountability – have been restated in subsequent reports, indicating that system-level change has often been slow or incomplete. In some cases, progress has been made (e.g. the shift to family-based breeding, expansion of QX challenge trials), but the absence of an integrated, industry-aligned delivery model has continued to hinder impact at scale.

The establishment of the Select Oyster Company (SOCo) in 2004 was potentially a positive step forward. The NSW Oyster Farmers' Association and NSW Farmers' Association (Oyster Section) formed SOCo to 'organise production and distribution of stock from the improved breeding lines and to ultimately take control of the management and future development of the current breeding lines' (Tynan 2010). SOCo's aspirations align with many of our current recommendations. However, by 2019, it was clear that the organisation was struggling. As Davis (2019) explained, SOCo had 'suffered considerable reputational damage over the years, to the point where a simple restructure may not overcome negative perceptions in the marketplace. It will be important moving forward to place a strong focus on transparency, accountability and the establishment of trust in relationships'. As a result of these, and other challenges, SOCo was disestablished and responsibility for the breeding program returned to the NSW DPIRD.

The following timeline (Table 1) lists key program events alongside completed reviews, tracking the evolution of both recommendations and their level of implementation. It provides a structure to understand missed opportunities, institutional constraints and the need for a more durable alignment between the NSW DPIRD and the oyster industry.

Table 1. Key events and reviews relating to the Sydney Rock Oyster (SRO) Breeding Program.

Year	Event	Result
1990	Mass selection breeding program initiated by NSW DPIRD	SRO breeding begins
1994	QX causes Georges River production collapse	
2002/04	QX causes Hawkesbury River production collapse	
2004/05	Triploid Pacific oysters permitted in QX impacted areas	Significant uptake and displacement of SRO
2004	SOCo formed to 'take control of the management and future development of the oyster breeding lines'	Industry partnership established, shared broodstock management and levy collection initiated
2007	Bunter (2007) review identifies limitations of line-based selection (e.g. lack of genetic parameter estimation) and the need for improved broodstock supply; QX resistance vs tolerance is questioned	Subsequent shift to a family-based approach with simplified breeding goals addresses some of the issues identified. Some genetic parameters still lacking
2008	First families created from within-line crosses	Family production proof of concept
2008	Significant NSW hatchery capacity established	Potential for program to transition from research to commercialisation
2012	Rye (2012) review recommends shift from mass to family-based selection	Family-based selection subsequently implemented

Year	Event	Result
2013	SOCo receives Cooperative Research Centres (CRC) funding to employ an operations manager	Continued intention for SOCo to co-manage and support the program
2014	Annual family breeding runs commenced under SOCo program	Family breeding model successfully established. See also FRDC project 2015-230
2014	O'Conner et al. (2014) review the genetic basis for SRO resilience	Identifies that QX-resistant oysters have improved overall resilience (to non-QX challenges)
2014	Schrobback et al. (2014) review identifies the need for structural reforms of industry management	
2019	Davis and Lewis (2019) review recommends an industry-focused breeding program, a reliable broodstock / spat supply and activities to promote grower uptake	SOCo disestablished and program responsibility returned to NSW DPIRD. Desired outcomes still outstanding (e.g. broodstock and spat supply, demonstration of value proposition)
2020	Accelerated SRO Breeding Research Project (FRDC 2016/802) completed	Enabled a 1-year breeding cycle for QX and increased number of families per run. Identified that family production 'remains a high priority for further research'
2020	NSW DPIRD takes on commercialisation role (from SOCo), tenders *Commercialisation Rights to Elite Families from the Sydney Rock Oyster Breeding Program*	NSW DPIRD remains responsible for the program in 2025. Governance challenges in the 'too hard basket'

2. Technical review objectives

This review was identified by the Sydney Rock Oyster Breeding Program Reference Group (SROBPRG) as a timely, independent assessment of the technical aspects of the SRO Breeding Program. The SROBPRG includes representatives from the NSW oyster industry, as well as hatcheries (within NSW and interstate), the NSW DPIRD and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The NSW Shellfish Committee and the NSW Aquaculture Research Advisory Committee (ARAC) noted and informed the development of this review.

The review was commissioned at a pivotal time in the evolution of the breeding program. Following more than two decades of technical progress, repeated reviews and persistent implementation challenges, the group has provided a mandate and an opportunity to ensure the breeding program can deliver more consistent, commercially relevant outcomes for the NSW oyster industry.

In this context, the breeding program has two purposes: (1) to realise the additional opportunities that genetic improvement can yield (such as faster growth); and (2) to protect or 'insure' the existing and future value of an industry (e.g. by providing disease risk mitigation). These gains benefit the individual companies that use breeding program material while promoting the economic growth aspirations of state and federal governments.

The overall objective of this review is to provide guidance to the NSW DPIRD and the Sydney Rock Oyster Breeding Program Technical Committee (SROBPTC) on whether the breeding goals and methods need to change to meet current and emerging industry challenges. We also address how operations could be changed to achieve new goals, including meeting the expanded market demand for the progeny of the breeding program. The report will guide the NSW DPIRD and industry stakeholders on the next phase of the breeding program by outlining the required steps. A plain language summary is provided in the initial section of this report.

Our review has inevitably strayed into the area of governance, as this emerged as a recurring theme throughout discussions and was often the 'elephant in the room'. We hope our external perspective provides some novel insight into solving the enduring challenges of program governance.

We have endeavoured to apply an objective lens to the program by focusing on what is being done well and what could be done better. We have also outlined the key aspects of a future 'best' program. We apologise where this may come across as critical but if the default is to carry on as normal, then the greatest value we can add is to identify where things could or should be done differently.

3. Key recommendations

This report provides significant detail with respect to the terms of reference, observations and many granular (technical) responses. To ensure our highest-level, structural recommendations are forefront, we have summarised the synthesised recommendations (full details provided in Section 6: Discussion) that we consider the most urgent and important. These are also prioritised with suggested implementation actions in Section 8: Recommendations and implementation plan. The key recommendations are a summary of (rather than a substitute for) the more detailed recommendations elsewhere in the report.

For many of the technical operations and decision-making processes, up-to-date or complete documentation was not readily available. This is challenging for reviewers but, more importantly, creates as an over-reliance on institutional knowledge and introduces the risk of 'process-drift'. We strongly recommend updating the SRO breeding manual 'program documentation' annually to provide a process map and rationale for all current operations. This should be provided to reviewers at the earliest opportunity in any future review processes.

3.1 Family production 'version 2.0'

The ability to produce 50 families per year for the last 10 years is a significant achievement, especially for such a challenging species. However, high attrition rates, and the suboptimal genetic gain that results from being forced to make selection and mating compromises, mean that the rate of genetic gain and production efficiency have significant scope for improvement. The inability to generate sufficient broodstock to ensure every family is eligible for commercial deployment is a serious consequence of the current hatchery production challenges.

Key recommendations

1. Invest in additional research to improve broodstock conditioning protocols in collaboration with the industry hatcheries that will also benefit from these improvements. While this research will be challenging, there are significant advantages for both family and commercial production if successful.
2. Scope, evaluate and implement opportunities to utilise next-generation family production methods. There are several low-risk collaboration options that could be used to evaluate the suitability of next-generation hatchery methods for SRO.

3.2 Reinvigorated traits and breeding objectives

The current goal of '70% QX survival and 30% faster growth with no loss of condition' has outlived its usefulness. There are perceptions that '70% QX survival' lacks commercial relevance, is overly simplistic and fails to account for the complex combinations of (multiple) challenges that SRO may experience.

There is almost universal interest in the concept of resilience as a breeding objective. Trade-offs between selecting for survival, growth and condition (especially within-family) are not always considered, nor are genetic correlation estimates (which quantify these trade-offs) readily available. There is scope for a more dynamic, interactive and ongoing discussion between the NSW DPIRD, aquaculture research groups, the core breeding program and industry stakeholders to ensure traits and breeding objectives are appropriate, relevant and adaptive.

Key recommendations

3. Leverage the SRO Breeding Program Technical Committee (SROBPTC) and the SRO Breeding Program Advisory Group (SROBPAG) to annually review high-level program progress, confirm selection indices are appropriate, identify directions for research that will underpin the future success of the SRO Breeding Program and update the SRO breeding manual.
4. Establish stronger connections with existing and future research programs that are aligned with the SRO Breeding Program.
5. Empower industry to play a greater role in guiding the technical direction of the SRO Breeding Program through co-developed technical publications, breeding workshops and extension.

3.3 Shifting the workload and expanding field trials

There is ongoing tension between the call for additional family evaluation trials and the lack of resources for trial maintenance and assessment. We believe NSW DPIRD staff are doing too much of the on-farm work that could be done better and more appropriately by industry (with formal recognition of the in-kind value of this assistance). This increased engagement would also give industry a clearer picture of breeding outcomes.

Key recommendations

6. Transition to a split-role model where oysters are handed to industry for field trials and subsequent assessment (with NSW DPIRD oversight). NSW DPIRD should provide upskilling, and breeding program context and extension to ensure trials have the level of robustness needed for generating accurate data.
7. Evaluate new trial designs that could enable more responsive trial assessment and the incorporation of new technologies (e.g. genomics).

3.4 Fixing deployment

The greatest risk to the program is probably the failure to reliably deploy the best available stock and *have that stock* demonstrate the breeding program's value proposition. Problems include not having enough good quality family broodstock available for all families and not establishing a coordinated supply chain through hatcheries to the farmer. Moreover, there is a lack of traceability of spat genetic merit through to the farm (which could demonstrate the linkage between good genetics and good performance). The success of the breeding program depends on the NSW DPIRD, the hatcheries and the farmers all working together; however, this is currently limited by a perceived lack of trust. The move to holding broodstock in Wallis Lake, while forced by natural events, is a step in the right direction.

Key recommendations

8. Recognise that collaboration and cooperation are required for the program's success. A strong partnership based on trust and a recognition of shared goals is essential.
9. Implement the recommended improvements to family production processes to ensure that all families are of sufficient number to be eligible (if selected) for commercial spat production. Industry should confirm the target number of broodstock per family needed for reliable commercial hatchery production, which may require the ability to strip spawn.
10. Complete the transition to full industry management of broodstock using the appropriate cost-sharing or recovery model (e.g. recognition of in-kind, direct cost recovery). This should include providing redundant repositories to mitigate biosecurity and environmental risks.
11. Implement a system for making genetic merit (e.g. estimated breeding values [EBVs]) accessible and transparent through production from hatchery to farm (see Appendix 4 for a working example: GF Plus™ system in New Zealand radiata pine breeding). This will enable clear demonstration of the breeding program value proposition.
12. Provide upskilling, extension and resources to ensure the entire supply chain (i.e. hatcheries, nurseries, farmers) understands the principles of deploying genetically improved stock, interpreting EBVs, trait trade-offs, the impact of culling and within-family selection, etc.

3.5 Governance partnership

Leadership and governance were repeatedly raised as systemic issues underpinning many of the other concerns raised. We saw a history of governance instability, a myriad of ephemeral committees, ineffective decision-making, a lack of trust, a high degree of fragmentation and a lack of connectivity. There is a perception that NSW DPIRD is responsible for everything and therefore gets blamed for everything. The levy appears as more of a cost-recovery 'big stick' rather than an enabler for program success and additionality. There was a sense that people fear another SOCo.

Partnership and leadership are needed across the program ecosystem, including at the governance, operational and technical levels. Sound partnerships will ensure that responsibility and accountability are distributed fairly, decisions align with the program's best interests, solutions are co-developed, benefits from the program's successes are shared by all involved and the program has a sustainable funding model. Industry should therefore be responsible for all on-farm aspects of the program, freeing up resources for researchers to answer the difficult questions. This will empower industry stakeholders to take an active role in learning how the program works and ensuring its success. Leadership entails good decision-making and overseeing best practice through regular self-review. Seeking independent advice, fine-tuning processes and challenging internal assumptions are also important. An emphasise should be placed on *what's good for the program is good for everyone*.

Key recommendations

13. Urgently establish a formal partnership between industry and the NSW DPIRD, beginning with a memorandum of understanding and partnership principles to build common ground. The NSW Farmers' Association was suggested as a potential partner to represent industry (but this is not necessarily the only or best option). The new partnership should be responsible for leading operational decision-making, particularly decisions relating to connectivity along the breeding program supply chain (e.g. NSW DPIRD, hatcheries, nurseries, farmers). There is scope for an 'independent' manager to provide oversight and coordination across the wider program.
14. Use this partnership to facilitate and implement the other review recommendations, such as shifting the trial and broodstock workload to industry. The partnership should seek, leverage or reallocate funding to implement relevant research-based recommendations. A sound and enduring partnership will give government the confidence to invest in the program as a generator of regional economic growth and as ready-response insurance against future challenges.
15. Ensure that the SROBPTC is delegated a more active role in overseeing and reviewing the operation of the nucleus breeding program, including family production, assessment, genetic analysis, and new research or tool development (e.g. genomic selection) opportunities.
16. Formalise overarching intellectual property (IP) principles, including ownership of existing material versus material originating from any new partnership. A spat certification process may help provide confidence that only legitimate users have access to spat from the breeding program (and / or have paid a levy to access this resource).

4. Methodology

4.1 Reviewer background and approach

The authors of this review have extensive knowledge of selective breeding program design, implementation and management, as well as experience with industry engagement across multiple species in the aquaculture, livestock and forestry industries (see Appendix 2).

The review approach includes analysis of key program documents (including the SRO breeding manual and the SROBPAG 'Breeding Program issues and opportunities paper'), site visits, interviews with NSW DPIRD staff and industry stakeholders, and a comparative review of international breeding program models assessed by the reviewers. Broadly, the reviewers sought to understand what was and wasn't working well, and what the 'best' future state might be.

We created the following working definition of breeding program 'purpose' as a benchmark to assess the performance of the SRO Breeding Program and identify opportunities for improvement:

> *The overarching goal of a genetic improvement programme is to deliver sustained, commercially relevant genetic gain that strengthens industry performance, resilience, and profitability.*
>
> *It achieves this by selecting for commercially valuable traits, ensuring effective deployment of improved genetics, building responsiveness to new challenges and opportunities, supporting cost-effective delivery systems, and generating knowledge and capability that benefit both current and future operations.*

4.2 Review journey

Preconception and framing

This journey began with initial stakeholder discussions (including outlining the need for the current review), an analysis of existing documentation and previous reviews, and a study of the SRO industry. Reviewers inevitably bring their own experiences and preconceptions that create a lens through which to view and frame the 'SRO story' as it evolves. Therefore, we sought to test these 'assumptions' at every opportunity.

The initial impressions were of an industry with significant potential but a multiplicity of evolving challenges, and a breeding program that has come a long way in terms of operational improvements and outputs. However, we perceived a history of governance instability, a myriad of committees, ineffective decision-making, limited trust, challenges with broodstock supply and a lack of a demonstrated value proposition. Many of these issues were seen as related, highlighting a degree of fragmentation and lack of connectivity within the breeding program 'ecosystem'.

Discovery

Site visits to NSW DPIRD and Port Stephens, combined with structured and informal interviews with farmers, researchers, hatchery operators and managers, provided opportunities to understand the breeding program's operational context. The diversity of perspectives revealed both points of tension (e.g. farmer confidence vs technical delivery) and alignment (e.g. commitment to long-term improvement).

Every interview highlighted the overall dedication to positive outcomes. The NSW DPIRD team were working above and beyond to deliver benefit to industry but were resource-stretched. Most industry stakeholders identified the value the program could potentially deliver, but they rarely identified the benefits in practice. We learnt that QX was more complex than simple survival, and that improvements to the (broodstock) deployment pipeline had already been implemented (noting that this was in part by necessity following the arrival of QX in Port Stephens). Both communication and information flow emerged as significant issues.

Refinement and reframing

As the review progressed, we refined and re-evaluated our thinking and assumptions. A notable example was the shift in our approach to QX disease, which was reframed from a singular view of a binary survival trait to a more nuanced understanding of resilience, performance under challenge and physiological capacity, which have a direct impact on marketability and ultimately survival of SRO.

The most significant shift was the recognition that many program issues were not technical, but structural and relational. This led us to reframe the challenge from 'fixing delivery' to 'rebuilding partnership'. Concepts such as mutual accountability, shared governance and additionality emerged as necessary conditions for developing a breeding program capable of evolving with its industry.

Implementation lens

Finally, the review shifted from diagnosis to identifying solutions. The main questions asked were: *What can change now? How can we help make this change achievable*? *What preconditions are needed to realise future gains?* This implementation lens forced us to identify tractable reforms and pathways forward, while also acknowledging longer-term strategic shifts (e.g. resilience-based selection, genomic integration, industry co-leadership).

4.3 Reporting

A draft review report was circulated to the NSW DPIRD, SROBPAG and SROBPTC for comment and feedback. Two weeks were allowed for review and feedback on the draft, which was extended by a further week. Final responses were received in week four, and these included feedback on technical detail, reviewer knowledge gaps and answers to questions in the draft. Responses on the overall findings of the report and key recommendations were almost exclusively positive. There was some uncertainty regarding next steps (including their assigned responsibility) and therefore additional implementation detail was provided (see Section 8: Recommendations and implementation). The final report also includes a brief plain English summary.

5. Results

The results of this report are presented in two sections:

- Breeding program design elements (see Section 5.1) is an analysis of program outputs and processes against a standard set of breeding program design elements.
- The sections that follow (Sections 5.2–5.11) contain our diagnostic findings with respect to the terms of reference (Appendix 1) and include initial reviewer responses that were formulated prior to refinement and reframing.

The discussion (Section 6) synthesises these findings, presenting the responses as overarching themes and recommendations. Key recommendations are presented in Section 3 and prioritised in Section 8 with suggested implementation actions.

Table 2. Recommendation levels and locations in the report.

Recommendation type	Level	Section
Reviewer response	Granular	Results (Section 5)
Synthesised	Themed	Discussion (Section 6)
Summarised	Priority	Key recommendations (Section 3)
Implementation	Priority with actions	Implementation plan (Section 8)

5.1 Breeding program design elements

The review evaluated the technical aspects of the SRO Breeding Program from the perspective of the following standard breeding program design steps:

- Breeding objective
- Trait definitions
- Genetic evaluation and parameter evaluation
- Selection and mating design.

This technical assessment is based on material supplied by Dr Curtis Lind (CSIRO), the SRO breeding manual (Dove 2021), and the Bunter (2007) report. It has also been informed by discussions with Dr Mike Dove, Dr Peter Kube and Dr Laura Parker. Note that completing and updating the SRO breeding manual to formally document the program’s processes and decision-making should be a priority.

Definitions:

- Breeding objective refers to what changes are being targeted – which oyster traits do we wish to change through selection.
- Indicator traits refer to the attributes measured on some / all oysters that are used in genetic analysis to predict the actual breeding objective traits.

Breeding objective

The SRO breeding manual (section 1.3, p. 8) states:

> The breeding goal for the nucleus is 70% survival to a single QX disease exposure, 30% increase in growth with no regression in meat condition or shell shape.
>
> The economic weight for QX disease resistance is twice that for growth and meat condition.

While these statements are reasonable, the figures were not necessarily intended to serve as a formal breeding goal. A selection index (2 × QX + 1 × Growth + 1 × Condition) based on a desired gains approach was derived with the expectation of annual adjustment to reach the desired gains. The process for determining the goals and weights is not documented in the manual.

The inclusion of 'no regression in meat condition or shell shape' indicates that whatever index is applied, its use in selection should result in no genetic change for the two traits.

Traits and trait definitions

The traits reported in the latest CSIRO analysis (Lind 2025a, 2025b) are described in Table 3.

Table 3. Indicator and breeding objective traits for the Sydney Rock Oyster Breeding Program.

Indicator trait (recorded, analysed and used to predict breeding objective trait)	Trait code	Breeding objective trait
Unit survival of oysters on QX-challenged field sites at 8 months	QX_SPAT	QX survival (spat)
Unit survival of oysters on QX-challenged field sites at 20 months	QX_ADULT	Not in breeding objective
Oyster total weight (g) at 3, 10, 14 and 20 months	WT_TOTAL	Growth
Wet weight condition index at 14 and 20 months (meat weight/total weight)	CI_TW	Condition
Shell width index (width/length)	W_INDEX	Shell shape (monitoring trait)
Shell depth index (depth/length)	D_INDEX	Shell shape (monitoring trait)
Unit survival of oysters on winter mortality sites	SUR_WM	Not in breeding objective
Oyster total weight based on selected top x% heaviest oysters	WT_SEL	Not in breeding objective
Condition index based on selected top x% heaviest oysters	CON_SEL	Not in breeding objective

Note the 'SEL' traits measure their respective traits (weight and condition index) for a sub-set of animals selected (based on weight) to use as broodstock for producing subsequent generations.

The final report of the 'Accelerated Sydney rock oyster (SRO) breeding research' project (Dove 2020) provided detail regarding winter mortality (WM):

> Given WM is likely to remain a significant issue for sections of the SRO producers, the continuation of a routine WM field challenge progeny test for SOCo could be considered as an opportunistic activity is it does not incur a significant additional cost. If future episodes of WM become more severe, SOCo would then be well placed to respond in a timely fashion.

While we understand that winter mortality trials have not continued, we would highlight the value of winter mortality assessments, as the disease impact on SRO can be significant. Moreover, the disease may re-emerge and it is heritable. Further trials could explore the potential of breeding for dual winter mortality / QX resistance and investigate winter mortality as a useful component of general resilience.

Consultation with industry encouraged the perspective that disease resistance traits could usefully be captured under a more general trait reported as 'resilience'. This would effectively capture survival, ideally at different ages and from recording at different sites. As such, it would in technical terms be an index, the composition of which would vary by year according to what actual causes were predominant in each year–location. This approach has the technical disadvantage that selection pressure on any one cause of death would be weakened – depending on trait variances and genetic correlations between traits – but would have the potential advantage of generating a more cautious predictor of general survival or fitness.

This concept – exploring a resilience breeding value – would not lessen the selection emphasis on survival (i.e. the cost of lost oysters is the same regardless of why they die); however, this revised approach would lead to a wider recording program with more test sites. In turn, this would likely increase confidence in the value of EBVs for resilience relative to QX. It is important to note that the perception that the QX resistance of SRO is not a good predictor may be unfair, as even the most resistant oysters will likely succumb under conditions with high and multiple stressors.

The program should aim to collect data at multiple points in the life cycle to monitor weight, condition and survival. This is counter to the general principle of finding the minimum level of recording consistent with useful EBVs, and the observation that for some key traits, across-years' genetic correlations are at least moderately high. However, given the observations that outcomes for resistant oysters seem to vary across sites and years, with uncertain impacts of various stressors, additional data will support more insight and, just as importantly, a greater understanding and sense of ownership across the industry.

It should be noted that if expansion of site recording is not possible, the present approach is valid.

Genetic evaluation and parameter estimation

This section draws on the reports provided by CSIRO (Lind 2025a, 2025b) detailing the analysis models and genetic parameters obtained in the 2024/25 year–class analyses.

First, both univariate and multivariate heritabilities are presented (Table 4) – the interpretation being that univariate analyses are conducted as a data checking step prior to the multivariate analysis, which generates the family EBVs used in the selection index.

Table 4. Sydney Rock Oyster Breeding Program heritability estimates.

Trait	Univariate heritability	Multivariate heritability
Condition (CI_TW)	0.27	0.29
Depth	0.47	
D_Index	0.66	0.68
Length	0.61	
Width	0.46	
W_Index	0.47	0.48
Wt_Total	0.63	0.63
QX_Spat (underlying scale)	0.25 (0.45)	0.26 (0.46)
QX_Adult (underlying scale)	0.24 (0.40)	0.24 (0.40)

Relationships among traits are presented in two ways. Formal (multivariate) genetic correlations are shown in Table 5 and correlations between EBVs in Table 6. Note that multivariate genetic correlations between production and QX traits are not estimated.

Table 5. Heritabilities (diagonal) and genetic correlations (lower matrix) for Sydney rock oyster performance traits. Includes data up to year class (YC) 2024 for QX spat survival and up to YC 2023 for all other traits. Data source: Lind (2025a, 2025b).

Trait	WT_TOTAL	W_INDEX	D_INDEX	CI_TW	QX_Spat	QX_Adult
WT_TOTAL	0.633					
W_INDEX	0.075	0.484				
D_INDEX	-0.093	0.665	0.676			
CI_TW	-0.525	0.012	0.151	0.289		
QX_Spat					0.256	
QX_Adult					0.617	0.243

Table 6. Estimated breeding value (EBV) correlations for Sydney rock oyster performance traits: correlations lower matrix. Includes data up to year class (YC) 2024 for QX spat survival and up to YC 2023 for all other traits. Data source: Lind (2025a, 2025b).

Trait	WT_TOTAL	W_INDEX	D_INDEX	CI_TW	QX_Spat	QX_Adult
WT_TOTAL						
W_INDEX	0.12***					
D_INDEX	-0.40***	0.50***				
CI_TW	-0.65***	-0.07**	0.41***			
QX_Spat	0	-0.02	0.02	0.31***		
QX_Adult	-0.04	-0.06**	0.05*	0.35***	0.92***	
WT_SEL	0.88***	0.10***	-0.35***	-0.59***	-0.02	-0.05*

Correlations between morphometric traits are as expected, including a negative correlation between total weight and condition (where total weight is the denominator for the condition ratio calculation). Reassuringly, there is little or no negative correlation between QX and growth, and a positive correlation with condition index.

Curtis Lind indicated that genetic groups are fitted in both the univariate and multivariate models. An explanation of the genetic group strategy should be included in the breeding manual, along with the advantages and disadvantages of the approach. Our understanding is that genetic group effects are added to the family solutions (EBVs) to arrive at the final EBVs used in selection. The evolution of genetic group composition is shown in Figure 1.

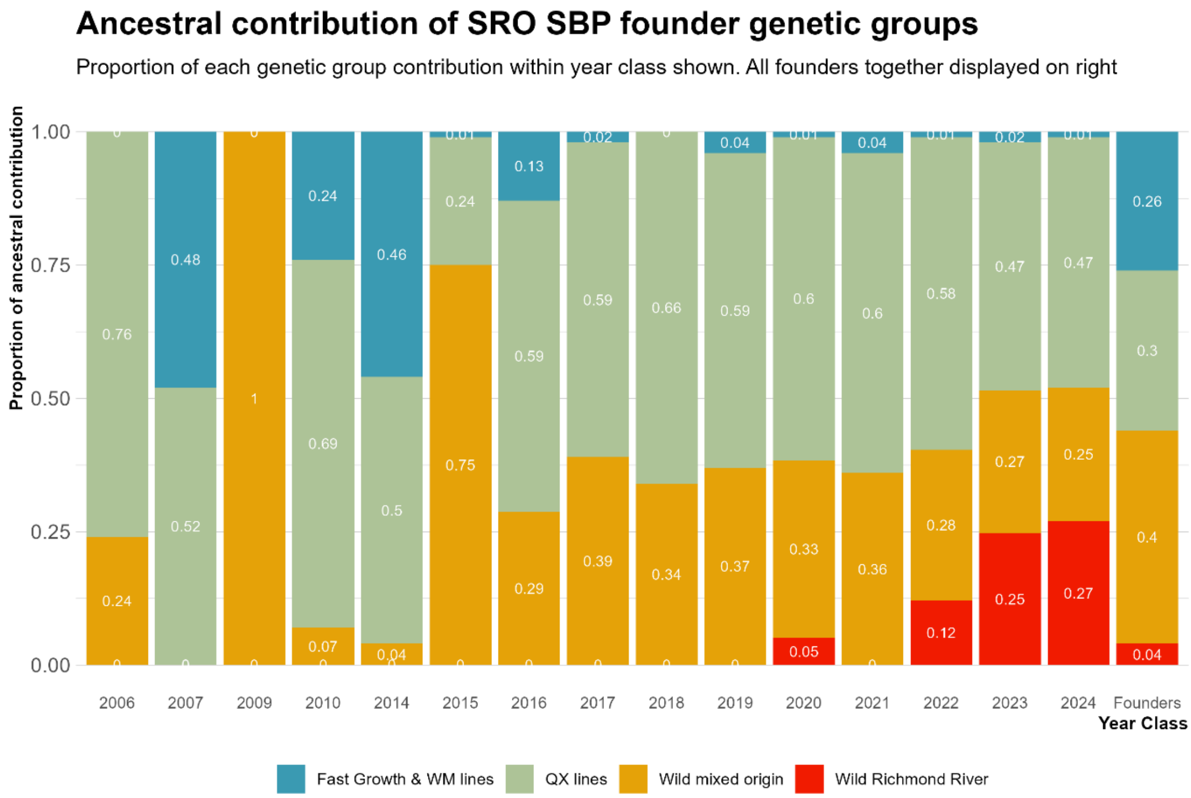

Figure 1. Genetic group composition and evolution over time. Source: Curtis Lind, with permission.

Lines developed in the SRO Breeding Program have contributed 60–70% of total genetic composition throughout the period shown in Figure 1.

A consideration for future research, assuming data collection at multiple sites and times is possible, is to evaluate random regression models for the development of mortality, whether from identified causes or not, against environmental variables such as salinity, water temperature and pathogen load. This approach essentially evaluates animals' genetic sensitivity to the environmental variables, expanding the understanding obtained through simpler genotype-by-environment (G×E) analyses. The hypothesis would be that oysters (families) vary genetically in their ability to cope with environmental challenge, and that this ability is not a 'black-and-white' binary trait. The potential outcome would be an improved ability to target specific oysters (families) to specific environmental conditions, and to the extent that these can be predicted, reducing risk. A corollary would be the mapping of combinations of environmental variables over time in various estuaries, which seems possible from existing and ongoing water quality sampling data.

Such a project would be ideal for either a PhD student or a postdoctoral researcher; the latter could be especially valuable if there is a back-log of data either waiting to be analysed or partially analysed but not published.

Selection and mating design

The top approximately 50% (based on the selection index) of available families are chosen for crossing, with increased representation of higher performing families. An optimising mate allocation algorithm is used to determine family mating combinations. The algorithm enables user-controlled balancing of genetic gain and inbreeding. The SRO breeding manual does not document the process that is currently used.

As commented, the exact balancing is not reported. It would likely be useful for industry to have some understanding of the degrees of choice at this point – which in broad terms is described by the frontier genetic gain versus inbreeding (or co-ancestry).

Overall program design comments

In terms of basic approach, the current family selection system is sound and, based on the available technical evidence, is delivering the required results. This reflects well on the staff and industry who collect data within tight timelines and with limited resources. The genetic analysis is also being conducted appropriately.

There are several questions relating to the analysis that should be explained and documented, at least internally. It would also be beneficial to have a simple but comprehensive information pack for industry. While the previous communications material has been useful, improvements could be made to ensure communication is in the form and language easily understood and shared by industry stakeholders.

More importantly, two technical opportunities should be seriously considered – although both will require new approaches to overall NSW DPIRD and industry collaboration:

- Recording at more sites and at regular intervals. This work will underpin a 'resilience EBV' and lead to a better understanding of the overall ability of SRO to perform under a range of conditions. It will also identify how this ability develops through the life cycle and how it may vary across conditions.
- Scoping transition to genomic selection (not searching for specific markers of climate change or other traits). This can incorporate collaboration with, and / or learning from, Australian Seafood Industries Pty Ltd (ASI).

Finally, there is scope to explore internal NSW DPIRD collaboration with the Animal Genetics and Breeding Unit (AGBU) in Armidale. AGBU is a joint venture between the NSW DPIRD and the University of New England (UNE) and would be a valuable partner in supporting a PhD student and / or a postdoctoral researcher. This research pathway is particularly useful considering that AGBU have implemented multi-trait genomic selection in several species and have sound experience and knowledge of genetic variation (such as the random regression approach). It should be emphasised that the technical services delivered by CSIRO are robust –but there is also an existing internal collaboration that is currently underutilised. AGBU senior staff could contribute positively to the SROBPTC, e.g. Dr Kim Bunter who conducted the technical review in 2007.

Reviewer response:

- Prepare a simple document (and update the SRO breeding manual) to outline the breeding objective. The document should include: the targeted trait change; the traits recorded; the traits reported as EBVs; the index used for family selection, including predicted changes; and the mating strategy (the genetic gain versus inbreeding frontier and optimal balance).
- Clarify which parameter sets are used for EBV calculation, including defining the pros and cons of the genetic groups approach.
- Update the genetic trend reports, ideally since about 2000, and include an explanation of the units of each trait.
- Define a PhD or postdoctoral project to utilise all existing data and previous analyses to:
  - review, with industry, the current breeding objective – including explanation of the relevance of meat condition and shell shape development patterns
  - inform a multi-site recording strategy, and the benefit–cost of implementation
  - scope for random regression analysis of existing data – potentially informing site or environment-specific indexes
  - develop a 'resilience EBV', incorporating survival information from all sites and time points.
- Develop a strategy with industry (potentially as part of the proposed PhD or postdoctoral project) to share costs of multi-site, multi-time recording that is underpinned by clear protocols (it is likely many are already developed following the research and development work by Mike Dove and others).

5.2 Breeding program practices and procedures

Family production (including numbers of families)

Over the last 10 years (excluding 2021), an average of about 50 mostly full-sib families have been produced per cohort. In the last 3 years, from an average of 48 families per cohort, 38 per cohort have been of sufficient number to transfer to Wallis Lake as broodstock. On average, 21 of the 38 have been made available to industry for commercial spat production. This scale supports acceptable among-family selection pressure and maintains genetic variance. However, effective population size (Ne) and long-term diversity are constrained by practical and resource limits on the number of families carried through field testing and selection. From a selection and genetic diversity point of view, more families are always better. For reference, Cawthron's oyster and mussel breeding programs typically target about 80 families per cohort, with the expectation that > 95% of these will be available, with sufficient numbers, for deployment. ASI similarly targets > 80 families per year.

The combination of broodstock conditioning and spawning challenges, with subsequent family attrition, means that families resulting from a single cohort are not necessarily the top selections. Moreover, they may not be the critical crosses targeted in a mating design. Any move to genomic selection will exacerbate the challenge of obtaining sufficient gametes from target oysters (rather than targeting families where several oysters or mating opportunities per family may be available). As a performance metric, the number of families produced should therefore take into account how many of the targeted families (e.g. using top selections) survived through to subsequent evaluation and potential deployment. Improved mating reliability would enable, for instance, more half-sib families (e.g. two females mated with one male) yielding more robust genetic analyses. Dove (2020) stated that 'the highest priority for further development of the SRO BP is increasing the success rate of single pair mated crosses', which was reported to be 27% at that time.

Reviewer response:

- Evaluate all possible options to continue improving reliability of family production from broodstock conditioning, larval rearing, spat rearing and on-farm management.
- Report transparently the cohort outcomes (including families deployable).
- Evaluate effective population size per generation alongside development of a risk-based plan for minimum viable family number, accounting for QX exposure losses and deployment disruptions.

Family hatchery practices

Family production is conducted using 'static' protocols (i.e. batch culture) in controlled hatchery conditions with significant effort to avoid pathogen contamination and cross-contamination between families. Variability in the success of spawning (related to broodstock conditioning), fertilisation / incubation, larval rearing and settlement has led to inconsistent family survival (see previous Section: Family production). This makes it difficult to optimise use of the available genetic pool and substantially increases the effort required to produce each cohort (e.g. 1.5–2 weeks for spawning). Note that inconsistent family performance may also arise from suboptimal hatchery processes and subsequently confound on-farm genetic evaluation. Using traditional static systems for conditioning, larval and spat rearing should be evaluated against next-generation (e.g. flow-through) systems to identify scope for reliability and performance improvement. While there may be challenges for SRO, Cawthron has used these systems for 25 years across multiple species, yielding increased reliability, scale, efficiency and improved genetic outcomes. Recent innovations in bivalve fertilisation and incubation practices may potentially offer additional reliability and yield improvements.

Examples of generic losses typically expected during family production are shown in Table 7. Many of these challenges and subsequent suboptimal outcomes were noted by the NSW DPIRD hatchery team, identifying potential for future improvement and optimisation.

Table 7. Generic shellfish hatchery challenges and potential consequences.

Process	Potential challenge(s)	Suboptimal outcome(s)
Broodstock conditioning	Not all oysters / families are in condition	Multiple spawnings (increased workload) Best genetics may be unavailable
Spawning	Not all oysters / families spawn	Multiple spawnings (increased workload) Best genetics may be unavailable
Gamete handling	Egg or sperm quality suboptimal	Fertilisation unreliable Only some families successful
Fertilisation	Suboptimal water quality	Fertilisation unreliable Only some families successful
Incubation	Suboptimal water quality	Incubation unreliable Fewer families and fewer larvae per successful family
Larval rearing	Attrition (families and larvae per family)	Fewer families and fewer larvae per family produced
Spat settlement and rearing	Attrition (families and spat per family)	Fewer families and fewer larvae per family produced
Broodstock deployment	Attrition (families and spat per family)	Insufficient broodstock for commercial-scale deployment of all families

Reviewer response:

- Resource efforts to improve the reliability of family production, both in terms of number of families and achieving a consistent number of spat per family.
- Review all hatchery protocols to identify areas for potential improvement or further research to increase reliability.
- Engage commercial hatchery staff and other breeding programs in protocol development to improve knowledge sharing and industry co-ownership.

Family field deployments

Field deployment is logistically complex and vulnerable to environmental disruptions (e.g. freshwater events). QX challenges are sporadic, unpredictable and sit within a multifactorial environmental context. In addition, Family × replicate designs require significant farm space and effort to maintain. The QX exposure protocol has been adapted over time, but the reliability and consistency of the exposure remains in question. Evaluations may be timed to suit logistics (e.g. optimal hatchery timing) rather than optimised for data quality. Site selection is not always sufficient to distinguish genetic from environmental effects. Limited resourcing for assessment and maintenance creates a tension between workload and the need to evaluate performance across more sites, environments and sporadic disease challenges. Currently, only one site is used for harvest attribute (e.g. growth, condition) assessments. This provides no redundancy if that trial site is lost (e.g. through biosecurity events, natural disasters, operator error).

Reviewer response:

- Re-evaluate field deployment strategies – especially for QX exposure – to ensure appropriate representation of growing environments.
- Given that current field trials are already resource-stretched, incentivise industry to increase their responsibility and workload (as a recognised in-kind contribution) to ensure field trials are carried our efficiently and accurately. This should include in-field data entry or updates by those collecting the data. Industry stakeholders and NSW DPIRD will need to reach a consensus on what constitutes best-practice for trial operation and maintenance.
- Alongside a small number of 'core' sites, consider new trial designs, such as genomic options for reduced footprint (mixed families within replicates) 'take-it-or-leave-it' field trials that are assessed opportunistically and only if a challenge occurs at that site or farm.

Measurements taken

An initial measurement of average group weight at 3 months (pre-QX deployment) is followed by individual morphometric and tissue measurements at about 10 and 16 months. These include whole weight, shell dimensions and tissue weight (wet). No early shell shape or dimensional data are captured pre-exposure. The top 75% of high-growth oysters are retained for post-deployment measures. While this culling before EBV estimation is contrary to best practice for unbiased evaluation of family performance, the 25% of 'runts' may cause even greater bias if not excluded from the trial. Most of the assessment burden is carried by the NSW DPIRD. The reviewers frequently heard that this was a significant resource burden that limited expansion of trial sites. There is pressure on the QX assessment pipeline to complete the assessment and analysis in time for incorporation of the previous year's families into the current year's crossing based on phenotypically derived EBVs. There was a suggestion that bringing the QX assessment forward to accommodate this requirement may not be optimal timing for phenotypic assessment.

Data are collected for research purposes (e.g. climate change adaptation) or by industry on farm. Currently this is not formally utilised by the main breeding pipeline.

Reviewer response:

- (Re-)evaluate commercial relevance of trait definitions (e.g. QX resistance vs resilience).
- Determine the genetic gain cost–benefit of an annual measure-and-select cycle for QX vs using non-phenotypic EBVs and optimal conditioning for initial selections.
- Explore all options for industry to take increased responsibility and ownership of the assessment workload, with appropriate technical (extension) support and acknowledgement of the value of this critical in-kind assistance.
- Consider incorporating all available data in the analysis pipeline.
- Investigate extending trait development research to identify proxies associated with QX resistance. The correlation of extended low-salinity events with QX mortality hints at options for selecting low-salinity tolerance or endurance as measurable traits associated with QX resilience. These could first be assessed by laboratory assay to minimise additional on-farm workload.

Genetic analyses

EBVs are computed as performance data become available. Standard ASReml analyses are used for univariate analysis of individual traits and bivariate analyses of multiple traits in individual trials. Data are pipelined via a robust database system, followed by extensive validation and outlier checking. Comprehensive data summaries flow back to the NSW DPIRD.

A reduced set of genetic groups are utilised (and adjusted for) to take account of differential performance depending on stock origin. We have found this is useful for identifying differences in performance of genetic groups as a research question (e.g. 'Is Richmond River stock better?') but inconvenient when estimating EBVs. The decision process for including genetic groups should be documented. G×E effects or spatial environmental covariates are not included in models, and this may be (understandably) due to the lack of sufficient data for estimation of G×E effects.

Genetic correlations are not formally estimated for all trait combinations (e.g. growth and QX survival), although plots and correlations of EBV pairs are always summarised for these combinations (including disconnected trials such as growth rate and QX survival). This information is extremely useful for assessing the risk and / or benefit in culling decisions, whether made within the program or by industry stakeholders in their stock selection – 'If I select the bigger oysters within a family, what impact will this have on condition and QX survival?' While some of this information is available in the cohort summaries, it appears lacking in the public domain and therefore may not be available to end-users. This suggests an opportunity to upskill end-users in the application of breeding program knowledge, such as interpretation of genetic parameters.

Reviewer response:

- Implement routine estimation and dissemination of heritabilities and genetic correlations for all traits.
- Fully document all analysis procedures and decision processes (in the SRO breeding manual).
- Evaluate the potential for multi-environment models or reaction norm approaches to improve prediction accuracy.
- Consider incorporating all available data (e.g. from family-based salinity trials) in the genetic analysis to better integrate ongoing resilience research with the breeding program.

Data management

The CSIRO SRO breeding database is used for managing all individual trait data collected via formal breeding program family assessments. This includes QX survival as well as harvest data on growth, meat and shell weight, and condition. There is a robust pipeline in place, which includes comprehensive data quality checks through to the ASReml analysis.

Aside from the formal family assessments, other data may be collected in the course of experimental work (e.g. in relation to climate change), but these are not included in the routine breeding data analysis.

Reviewer response:

- While the core data management process is solid, consider additional exploratory analyses based on other biological and environmental research data being collected, including industry data.

Management of the overall breeding population

While the SRO breeding manual discusses mate selection and inbreeding limits, there is no clearly defined long-term breeding strategy covering mating structure, rotation plans or long-term maintenance of genetic diversity. The manual notes a goal of maximising selection intensity while keeping the rate of inbreeding below the generally accepted level of 1% increase per generation. The rules-based approach for managing inbreeding and optimising gain during mating is documented in the SRO breeding manual; however, we understand this has been superseded by the mate allocation software currently employed. Broadly, the top approximately 50% of families are selected with representation ranging from five candidates per family for the highest-ranked families down to one candidate per family for the lowest-ranked families. The mating allocation interface maximises genetic gain (based on the selection index) while maintaining inbreeding below a threshold.

Figure 2 shows inbreeding and co-ancestry trends for the period 2020–24.

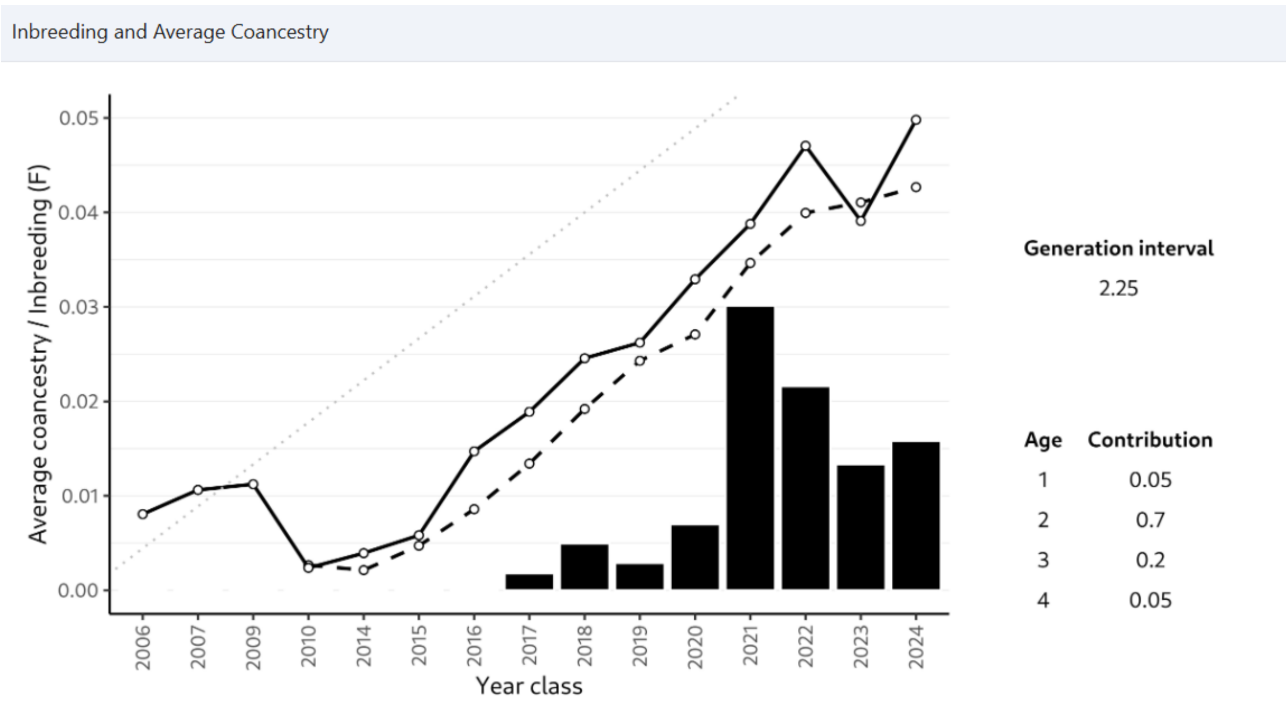

Figure 2. Inbreeding and co-ancestry for the Sydney Rock Oyster Breeding Program. Bars represent the mean level of inbreeding within each year class. The solid line represents the mean of family co-ancestry within each year class. Dashed lines represent the rolling average co-ancestry across multiple year classes weighted by the projected genetic contribution to future year classes. The generation interval is derived from the assumed genetic contribution of parental age classes. The diagonal dashed line indicates a rate of change of 0.01 per generation. Source: CSIRO, with permission.

The co-ancestry and inbreeding trends suggest:

- Average co-ancestry is rising by about 0.004 per year, or 0.01 per generation.
- Average inbreeding is rising but at a slower rate, noting that average inbreeding in the 2021-year and 2022-year classes was above the trend.

It is assumed that all extant families are included in the mate allocation runs – which should help manage co-ancestry.

Reviewer response:

- Continue to manage and monitor inbreeding within agreed limits while optimising genetic gain.
- Update the SRO breeding manual with current mate allocation principles and procedures.

Any other procedures directly related to the implementation of the breeding program

There is scope to improve the program's bi-directional communication efforts. For example, industry stakeholders have had trouble accessing information, while messages to industry are not always received or understood. There is scope to make more effective use of existing communication channels such as the SROBPTC and SROBPAG.

Another consideration we have highlighted in this report relates to the use of within-family selection. In the process of selecting broodstock to form new families – and selecting stock for commercial deployment – larger (faster growing) individuals are sampled from the families – a procedure aimed at improving growth rate. This generates a within-family selection post the actual family establishment, effectively increasing the selection pressure applied on growth. Noting the negative correlation of growth with condition (about -0.5), this likely applies negative selection on condition within families, thereby reducing the emphasis on condition. This effect is illustrated in Figure 3, which shows the genetic trends for weight and condition before and after the within-family selection (data from Lind 2025a and pers. comm.).

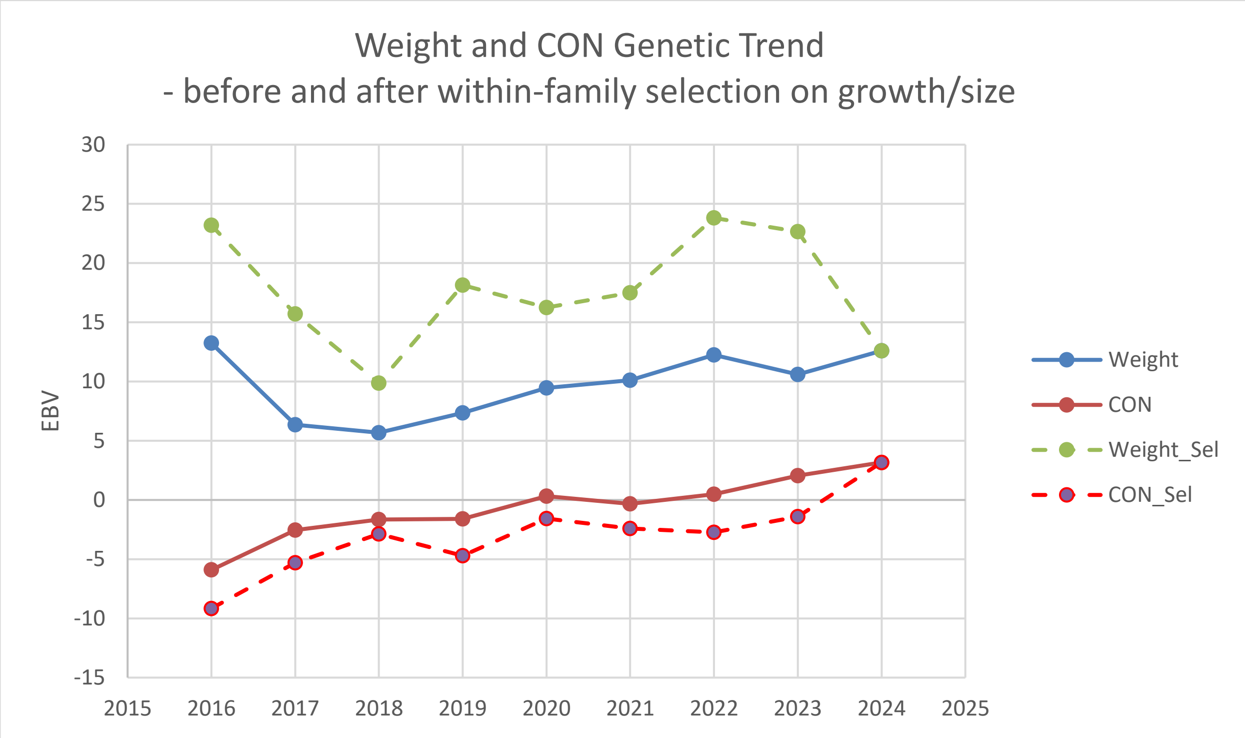

Figure 3. Effect of within-family selection on weight and condition estimated breeding values. The values for 2024 are before any within-family selection. Weight and condition (CON) are unselected weight and condition (i.e. family means), while Weight_Sel and CON_Sel are the same data adjusted for the impacts of within-family selection. Data source: Lind (2025a) and pers. comm.

Points to note are that while the overall selection goals are as discussed previously, more selection pressure than intended is likely being applied on weight (growth rate) and less on condition. The effect is that the genetic trend for weight is about 5–10% higher than initial family means, and for condition about 3–5% lower. All other things being equal, this will make achieving desired condition levels somewhat harder than expected.

Reviewer response:

- Provide increased extension and support to build industry knowledge of the breeding program operation and the technical implications of breeding decisions.
- Review and document all steps in the breeding and deployment process where culling or within-family selection occur to ensure any unintended consequences are identified and understood.

5.3 Current breeding objectives, breeding goals and selection traits

The current breeding program has largely focused on growth, condition and QX survival as primary traits. Traits such as shell shape, scope for growth and market quality have been discussed but not routinely included in selection indices or formally tracked over time. Winter mortality has been measured previously but is not currently seen as a priority.

Several stakeholders raised concerns that selecting solely for growth may inadvertently lead to undesirable shell morphology, poor survival under stress or variable meat quality. These issues align with our previous comments regarding genetic correlation and within-family selection, and commercial concerns: farmers value fast-growing oysters, but they also need robust performance across seasons and resilience to environmental fluctuations (e.g. salinity, temperature, disease pressure). Some stakeholders emphasised that QX resistance is not an issue for all farmers (at this stage).

Recent discussions suggest a growing interest in resilience as a breeding goal, encompassing both specific resistance traits (like QX survival) and broader performance stability across variable environments. However, this has not yet translated into a revised selection index or phenotyping strategy. A widened resilience focus could usefully incorporate winter mortality as one of its components which would also help maintain a watching brief on this potential disease threat.

Reviewer response:

- Consider expanding the breeding objective to include traits underpinning stress resilience (e.g. salinity, temperature tolerance).
- Implement estimation, dissemination and discussion of genetic correlations between all traits – especially growth, condition and QX resistance – to inform trade-offs and optimal broodstock management practices.
- Maintain a watching brief for winter mortality.
- Evaluate the impact of data collection protocols on selection bias during phenotype recording and EBV estimation.
- Confirm that the multi-trait selection index aligns with both the NSW DPIRD research priorities and industry value drivers.
- Engage with industry stakeholders to prioritise traits and understand trade-offs, e.g. through extension, facilitated workshops or surveys.
- Explore G×E and reaction norm approaches to better model resilience across farm environments.
- Consider using proxy traits (e.g. stress-response assays) to enable higher-throughput phenotyping of complex traits.

5.4 Procedures in place for broodstock supply for commercial propagation

Broodstock for commercial propagation are sourced from selected families (where there are sufficient numbers), primarily from the NSW DPIRD holdings. The process is centrally managed by the NSW DPIRD. The arrival of QX disease in Port Stephens necessitated the shift of the deployment broodstock repository to Wallis Lake, and this operation is under the management of East 33.

Concerns identified:

- Stakeholders frequently identified the disconnect between breeding program output, via broodstock and hatcheries, to subsequent commercial deployment of improved stock on farm as a critical issue for the program.
- The inability to source sufficient broodstock from the best-performing families is a serious constraint for hatcheries (and therefore the downstream supply chain).
- Some stakeholders commented that broodstock may be held too long or are not conditioned appropriately, compromising spawning success and highlighting the need for improved conditioning protocols. Other stakeholders suggested that broodstock conditioning should be the responsibility of the hatchery.
- There is poor alignment between broodstock availability, usage limitations and hatchery production requirements.
- In some cases, stakeholders suggested redundant decentralised broodstock holdings (e.g. an extended East 33 model) as a possible improvement.

While the centralisation of broodstock control under NSW DPIRD has operational advantages, it limits responsiveness to hatchery needs, and NSW DPIRD resources are shifted away from their core business. Hatchery production is highly seasonal and sensitive to oyster conditioning state. Mismatched broodstock delivery has undermined commercial production and delayed program deployment. There are a range of views regarding who should be responsible for broodstock conditioning. Ideally, hatcheries should have full control and responsibility for the conditioning process.

The lack of transparency around broodstock pedigree, EBVs and bloodstock availability has weakened hatchery trust and engagement. A more integrated model is urgently required.

Reviewer response:

- Implement shared broodstock planning calendars across the NSW DPIRD and commercial hatcheries to make it clear when broodstock are needed and will be made available.
- Improve the reliability of family production to ensure sufficient broodstock are available for all families.
- Establish decentralised, redundant broodstock holdings.
- Supply hatcheries (and farmers) with EBV summaries and options to select broodstock within defined genetic boundaries.
- Develop improved conditioning protocols especially for hatchery conditioning.

5.5 NSW DPIRD departmental needs from the breeding program

NSW DPIRD’s recently developed road map formalises its mandate and strong motivation to secure and grow the NSW SRO industry, recognising the industry’s potential growth and its strength as a contributor to the state economy. NSW DPIRD’s support of the breeding program as a ready-response tool underwrites the security of the current and future industry.

NSW DPIRD staff are highly motivated, both to help the industry and to advance SRO knowledge and innovation. The staff have publication expectations tied to their role classifications, formalising the importance of research to career progression. Moreover, NSW DPIRD staff at all levels are committed to the breeding program.

During the current review, resourcing was repeatedly identified as a constraint: ‘We would love to do more research but are too busy’; ‘Extension is important, but how do we fund it?’; ‘More sites would be great, but we are too busy with the ones we have now’. There is no clear pipeline for future program funding.

Currently, the NSW DPIRD is seen as the sole custodian of the program, bearing all responsibility and being assigned blame for downstream failures. As an alternative future governance model, a partnership between the NSW DPIRD and industry (e.g. the NSW Farmers’ Association) is viewed positively.

Reviewer response:

- Internally clarify NSW DPIRD’s preferred or core roles in the program, identifying where their unique capabilities and resourcing can deliver the greatest impact. For example, the core production of families, research to support the breeding program, data curation and industry extension appear to align well.
- Identify the areas of NSW DPIRD’s current work and responsibility that could be delegated or shared with industry or other stakeholders to spread workload and free up resources for NSW DPIRD’s core activities. For example, broodstock holding and deployment, and trial management and assessment are more suited to industry skills and resources (with appropriate guidance).
- If resources are limited, consider alternative funding mechanisms or models to enable research and improvements to the program that would benefit both the NSW DPIRD and industry. For example, the current levy as partial cost recovery does not incentivise industry to increase its contribution. A more effective model could include additional contribution (whether via the levy or in-kind support) that is viewed as an investment linked to additional benefit. Regardless of the funding model, demonstrating the value proposition for improved spat (compared to wild unimproved spat) is critical.
- Consider improving integration of research (e.g. on climate change) and breeding program objectives. For example, low-salinity tolerance or endurance may be needed as high rainfall events increase, and this could also be an underlying driver for QX survival.

5.6 SRO industry commercial and market needs

Priorities vary across SRO growers and growing regions. For some harbours, we heard that their main requirement was 'a little QX with growth and condition'. Others stated that they only needed growth and condition at this stage. Most farmers, however, have witnessed rapid change and are universally focused on maintaining QX resilience in the breeding population and fostering the ability to adapt. The overall requirement is that the breeding program must balance the varying needs of all the growers it services. The breeding index provides a single direction for the nucleus breeding program while still maintaining sufficient variation across traits (making up the index). This approach enables farmers and hatcheries to prioritise individual traits as needed.

When QX strikes, growth and condition are irrelevant – a dead oyster is of no value, and QX survivors may be unmarketable. Furthermore, having a significant proportion of unmarketable (and externally indistinguishable) oysters may render the entire harvest unmarketable. Sometimes it is possible to distinguish 'live but QX-affected' oysters based on their lack of a 'growth edge', but this is not always the case. A QX event can knock out a harbour for at least three seasons, until harvestable crop is again available to market. Not all farmers will have the operating capital to survive such a cashflow crisis.

Farmers often credited hatchery operators, and not the breeding program, for performance gains: 'I just want hatchery X's spat'. Stakeholders reported concerns about lack of traceability and feedback loops that would enable industry to relate genetic merit with on-farm performance. In particular, it is not always apparent which stock (genetic merit) is being grown on farm. Therefore, when there is a success (or failure), it may be difficult to attribute credit to the breeding program. This also makes it challenging to align a program levy with genetic merit.

This review also uncovered perceptions that 'the right things aren't being measured', and that QX survival, in particular, is disconnected from the on-farm reality where survival and marketability are both important. Farmers want to contribute to the success of the program by helping reconnect their on-farm reality to the breeding program.

Communication gaps have eroded trust in the breeding program and its output. Many stakeholders do not distinguish between genetic potential and hatchery practices. There is a perceived lack of extension material, on-farm trials and real-time data sharing, which limits NSW DPIRD's ability to build ownership and trust across the supply chain. The reviewers repeatedly heard, 'we told them x and y' but the message 'didn't get through'.

Overall, there is a perception that the NSW DPIRD is managing all aspects of the breeding program and is therefore accountable for everything. However, industry stakeholders need to be empowered to take greater responsibility and ownership for the program's outcomes. A partnership or co-governance model with clear authority and accountability will help rebalance this burden.

The SROBPAG provided specific industry-focused input via its 'Breeding programme issues and opportunities' paper (August 2025). The paper included key themes, which largely overlap with the review findings:

- Assessment and data collection should be more holistic, with greater consideration of real-world performance and tighter information integration along the value chain.

- The breeding program lacks structured or transparent governance. The SROBPTC and SROBPAG could be given greater responsibility for guiding program direction.
- Traits and breeding objectives need updating to reflect diverse and changing needs.
- Broodstock availability and reliability of spat supply are bottlenecks that threaten growers' confidence in the program.
- There is no formal IP framework to protect existing and future investment in the program.
- Decision-making tools and breeding program information (e.g. EBVs) are not readily accessible to farmers.
- Industry does not have a clear understanding of the value proposition for breeding program oysters.

Reviewer response:

- Develop a formal extension strategy, including fact sheets, EBV and genetic parameter summaries, and on-farm validation trials.
- Empower hatcheries and farmers to collect and contribute data that feeds back into breeding evaluation.
- Transition governance and responsibility to an industry co-leadership model (e.g. NSW Farmers' Association partnered with the NSW DPIRD) supported by an empowered SROBPTC and SROBPAG.
- Rebuild trust through transparency, co-investment messaging and shared goal-framing.
- Ensure a reliable spat supply, alongside appropriate supply chain transparency, to link genetic merit to performance and control access to breeding program IP.

5.7 Hatchery supplier commercial and market needs

Hatcheries (and nurseries) are the 'meat in the sandwich' putting them in a difficult but critical position in the supply chain. From the input perspective, they are challenged with variable broodstock quality (including very old broodstock), and constrained broodstock availability (e.g. number of oysters per family) and usage (e.g. natural spawning only). There are also broodstock conditioning issues and a lack of clarity around the breeding program value proposition. From the output position, the market pull is variable (because of the weak value proposition), and the lack of spat at critical timepoints can leave farmers frustrated. Moreover, there is no clear mechanism to market genetic gain, and the levy that must be collected by hatcheries is potentially absorbed rather than charged as a spat 'upgrade' cost.

The reviewers heard reports of delayed spat orders (for reasons outside the hatchery's control) that were no longer required by the farmers once the spat was available. It must be emphasised that a breeding program needs supply chain confidence for successful deployment.

Hatcheries may also suffer from the same spat production limitations observed in the breeding program (e.g. unreliable broodstock conditioning). Therefore, research to address these issues will benefit hatcheries and the downstream supply chain.

Reviewer response:

- Review the responses under 'Procedures in place for broodstock supply for commercial propagation' (see Section 5.4) to ensure coordinated and appropriate broodstock supply.
- Consider hatcheries as critical industry partners in any decision-making agreement or governance body – they are a critical component of the breeding program's success.
- Improve the flow of genetic information from the breeding program through the hatchery to the farm. A more transparent system would enable hatchery product differentiation (based on genetic quality) and third-party monitoring of germplasm usage, and farmers could make the connection between genetic merit and realised on-farm performance.
- Actions that demonstrate the value proposition for improved spat will help hatcheries differentiate their product from wild spat, reinforcing their value and importance in the lab-to-farm supply chain.

5.8 Genetic progress of the breeding program and success expectations

Key points identified:

- NSW DPIRD reports annual genetic gain within the nucleus population, particularly for growth and QX resistance.
- As of 2024, NSW DPIRD reported that genetic progress was close to meeting the program's breeding goals (noting that breeding goals should serve as intermediate waypoints rather than final endpoints).
- Visibility or benchmarking of genetic gain across farms or hatcheries is limited.
- Linkage of commercial spat to EBV profiles is weak or undocumented.
- Stakeholders are unsure how much of observed performance is due to breeding.

Genetic trends describe how the genetic merit of the population is changing over time. The following charts describe genetic changes for SRO in the 2016–24 year classes (Lind 2025a, 2025b) for:

- weight (WT_EBV, growth), width index (WI_EBV, shape), depth index (DI_EBV, shape) and condition (CON_EBV); Figure 4.
- QX in spat (QX_SPAT_EBV, survival %) and adults (QX_ADULT_EBV, survival %); Figure 5.

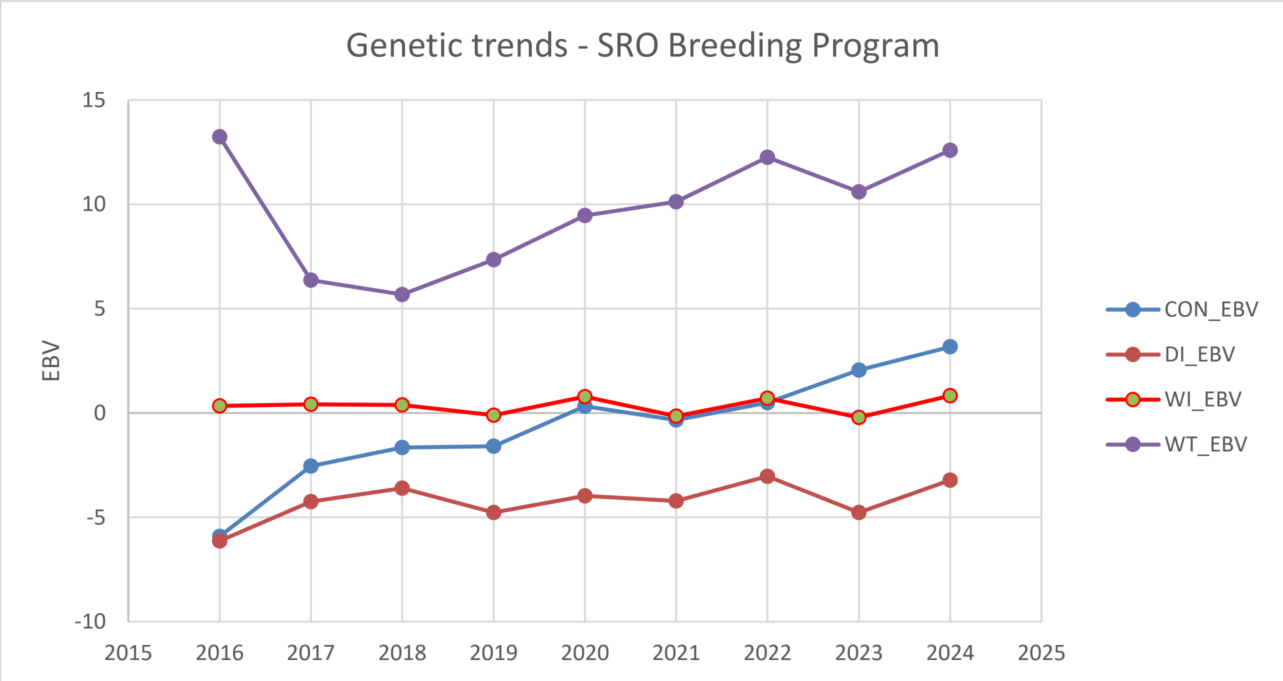

Figure 4. Genetic trends for production traits in the Sydney Rock Oyster (SRO) Breeding Program. Data source: Lind (2025a, 2025b).

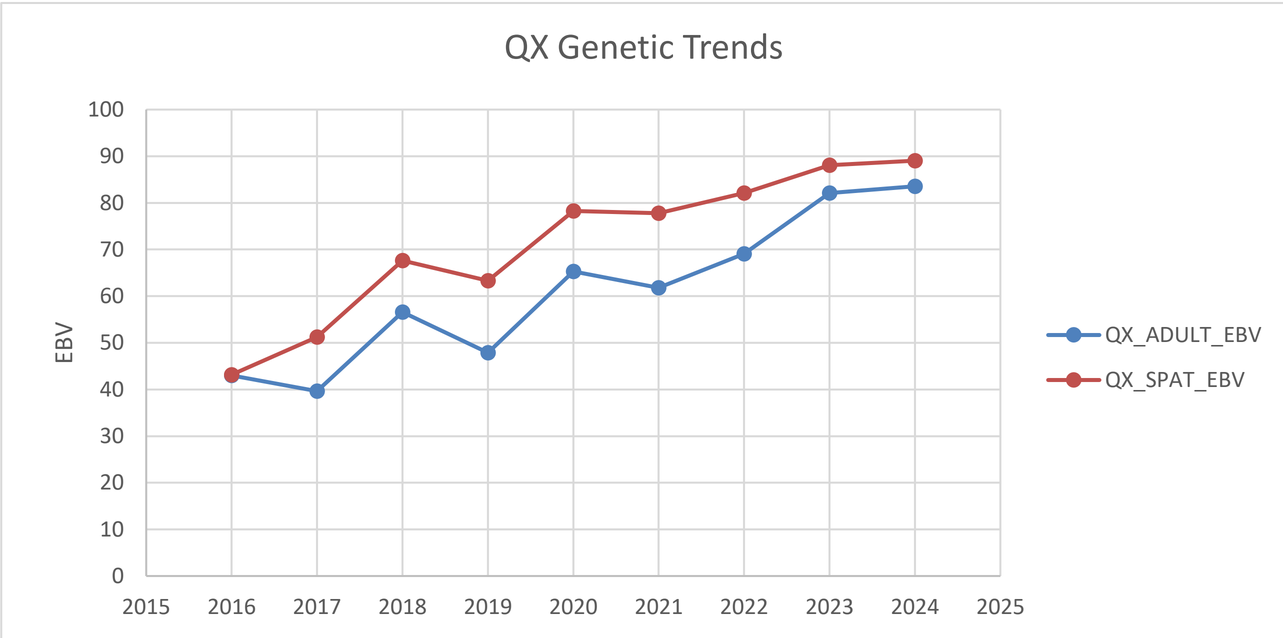

Figure 5. Genetic trends for QX traits in the Sydney Rock Oyster Breeding Program. Data source: Lind (2025a, 2025b).

Observations:

- steady genetic progress for weight following a decline in 2016–18
- steady genetic progress for condition
- essentially no genetic change in depth or width index.

For QX, three points are apparent:

- the overall level of survival is high – seemingly about 90% for QX_Spat and about 80% for QX_Adult
- the genetic correlation between QX_Spat and QX_Adult is high – Lind (2025b) records this as 0.62 +/- 0.06
- the genetic trend is continuing to be positive, although there may be a plateau in the last 2 years.

Following our review of past and current reports, we note that genetic trends are presented in different formats. For example, the April 2024 update (Figure 6) labels the y-axis 'EBV (% gain)', which is correct for the weight and condition series but not for the QX data series, where the y-axis is displaying EBV as percentage survival.

Where possible, clear and consistent reporting and communication should be used to provide confidence in the trend observations. This will also ensure that the information can be understood by all stakeholders.

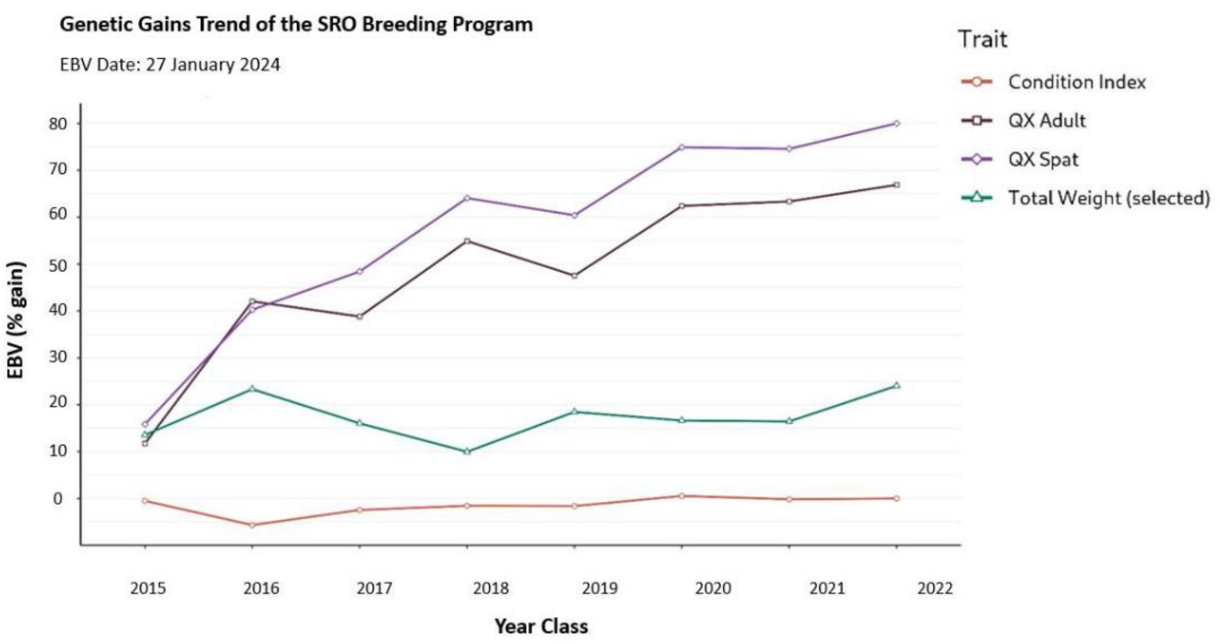

Figure 6. Overall genetic trends displayed as 'EBV (% gain)'. Source: Laura Parker, NSW DPIRD, with permission.

NSW DPIRD (2024) reported the following:

> … the current industry goal is to produce commercial oysters with greater than 70% survival through one QX disease outbreak and 30% faster growth, without changing meat condition when compared to a wild oyster. The DPIRD pair mated families produced in the 2022-year class were assessed in March 2024 and show that we are close to meeting these goals…

We understand the need to show effective progress but recommend caution when stating the breeding program is close to reaching its breeding goals, as this could imply the program is no longer needed. Additionally, end-users may argue that the breeding goals have not been reached because farm deployment of genetic gain lags significantly behind the gain shown in the family assessment data. Approaching the current breeding goals does however serve as an (overdue) waypoint check to update the program's journey. It is generally accepted that for almost all farmed species, where there continues to be genetic variation available for economically valuable traits, there is value in continued breeding. For example, decades of selection in horticultural and livestock improvement programs continue to yield genetic gain. Oysters are likely to respond similarly, and an effective breeding program should be viewed as an essential continuing contributor to industry investment and success.

Without a clear association of genetic merit with on-farm performance, genetic gain remains a faith-based theoretical construct for most SRO farmers. The program lacks credible benchmarking and independent validation, and farmers may not experience the benefits for themselves. However, improvements to the program could lead to farmers being its strongest advocates. Currently, the inability to confidently link spat batches to family EBVs post-hatchery hinders ultimate performance from being attributed to genetic gain. In turn, there is a failure to emphasise the value proposition. In this respect, it is very difficult to evaluate the on-farm genetic progress. Additionally, broodstock deployment issues may have severely constrained the translation of genetic gain from nucleus to farm. Ultimately, the true test is not whether the genetic trend line hits 80%, but whether the farmers using improved spat report greatly reduced losses when there is a QX event. There is scope to consider incorporation of benchmarking or control families in breeding runs.

Focusing on genetic gain within the nucleus (as reported by the NSW DPIRD), industry discussions and impressions question the commercial relevance of QX survival as it is currently measured (see Section 5.3: Current breeding objectives, breeding goals and selection traits) – particularly given the perception that QX-resistant families are still affected by QX. There are diminishing gains as survival 'tops out' toward 100%, but also the metric becomes less discriminating – all families are 'good'. Therefore, it could be argued that more sensitive measures (or more aggressive challenges) need to be employed, and these should be dynamically adjusted rather than set as a single target. For example, laboratory assays, stress-on-stress challenges and low-salinity proxy challenges could be considered as smart research-based opportunities to develop next-level QX metrics.

Regardless of the actual rate of gain (for any or all traits), we believe genetic gain could be increased though improvements to hatchery processes, as previously discussed. It is important to note that currently, there may be significant compromise in the ability to select from the best families, mate optimally and then carry all crosses through to the next generation.

Reviewer response:

- Consider implementing a more transparent system to link spat to EBV-pedigreed families (e.g. see the GF Plus™ system used for tree seed certification; Appendix 4).
- Consider establishing industry benchmarking trials to validate on-farm performance while noting these trials can be challenging.
- Consider developing readily available dashboards or reporting tools showing rolling gains and expected outcomes to make existing data more readily available.
- Measure realised program performance against theoretical performance (if optimal selection and mating is achieved) to identify potential scope for improvement. Specifically, the question that needs to be answered is, 'What is the gap between the best commercially available spat and the top-ranking families?'

5.9 Operational structure changes required to meet emerging business needs

Summary of evidence and perspectives include:

- Governance is almost universally seen as a key limitation and disfunction of the current program.
- Decision-making lags behind the business needs.
- The SOCo committee faced multiple challenges and was not the right solution at the time.
- NSW DPIRD is overburdened as both operator and decision-maker.
- Stakeholders support a new governance model with the NSW DPIRD as a partner, not owner.

The governance structure has repeatedly been highlighted in past reviews as it has struggled to evolve alongside industry. The current 'NSW DPIRD as caretaker' model is no longer fit for purpose. Effective breeding programs require shared and efficient decision-making, industry investment, technical oversight and vision.

The NSW Farmers' Association is a credible, representative organisation that is trusted and supported by the growers. It therefore has potential as a suitable industry entity to co-lead program governance.

Reviewer response:

- Establish a new governance body that is co-led by industry and NSW DPIRD.
- Clearly define roles, responsibilities, accountabilities and authority while separating delivery from oversight.
- Build industry co-investment mechanisms with transparent input and benefit sharing.
- Consider introducing transparent value-based pricing (longer term) based on EBV superiority.
- Leverage the SROBPTC to advise on breeding design and evaluation.

5.10 Implications of potential changes to selection technology

Evidence and perspectives include:

- The breeding program is not constrained by access to new technology.
- The notable problems arise from under-utilisation and unreliable deployment.
- Traceability tools, genomic selection and condition metrics are technically feasible but underused.

Instead of observing a 'high-tech' constraint issue, this review noted a need for reliable, consistent application of existing tools. Genomics could reduce the burden of QX challenge testing and support multi-trait selection – but only if robust data and pipelines are in place.

Reviewer response:

- Focus on the operational reliability of existing tools before investing in new technology.
- Consider piloting genomic selection with a small set of high-value traits (e.g. QX resistance), potentially via single nucleotide probe (SNP) genotyping to enable calculation of the genomic relationship matrix and estimation of genomic EBVs.
- Consider enhancing digital platforms for traceability, EBV access and communication.

5.11 Scientific understanding and knowledge base supporting the breeding program, and knowledge gaps requiring research

The breeding program is supported by sound scientific work, but several gaps remain:

- Published estimates and discussion of genetic correlations (e.g. growth vs QX resistance) are lacking.
- There is minimal G×E modelling despite environmental diversity.
- There is potential to develop resilience concepts and understanding in breeding design.
- NSW DPIRD's ability to carry out research to support and extend the program is resource limited.
- There is a significant body of undocumented institutional knowledge at risk of being lost as staff retire or shift into new roles.

There is significant potential to expand the SRO knowledge base including several areas where additional research would provide rapid payback to the efficiency and output of the breeding program. These include continuing to improve family hatchery production; understanding the physiological basis for QX resistance and general resilience; and optimising breeding strategy. While current research effort is focused on producing and assessing families, it is challenging to resource these important but more fundamental research themes.

We believe that implementation of several review recommendations could provide a pathway to resource these research needs. In particular, an NSW DPIRD and industry partnership, which would shift more on-farm workload to industry, and a new co-funding model, which incentivises additionality rather than simple cost recovery, could potentially free up or provide further funds directed toward specific research problems and opportunities. Ultimately, the demonstrated on-farm success of the program will generate additional revenue through increased market penetration (e.g. out-of-state sales).

The SROBPTC should play a more proactive role in both coordinating and driving opportunities for enabling research that is aligned to the breeding program, or that leverages the program's output (e.g. families).

Reviewer response:

- Ensure genetic correlations across traits and environments are readily available and well understood by researchers and industry.
- Consider developing a resilience breeding framework, incorporating scope for growth and multiple stressors, and leveraging NSW DPIRD's climate change research capability.
- Consider improving trial designs to support G×E analyses and cross-site evaluation.
- Support scientific publication output, both for program credibility and staff development.
- Leverage industry support (through in-kind, cash and levy contributions) to enable research and broaden the program's scope.
- Empower the SROBPTC to play a more proactive role in coordinating research needs and opportunities.
- Ensure all existing knowledge and processes are captured (e.g. in the SRO breeding manual).

6. Discussion

In the discussion, we synthesise the issues, opportunities and responses identified in the report to generate more holistic recommendations that address specific emergent themes. These are further summarised and prioritised with suggested implementation actions in Section 8: Recommendations and implementation plan. Some of these actions could potentially be supported through joint NSW DPIRD and industry FRDC-funded research and development program(s).

6.1 Reliable family production

Production of families has the potential for significant advancement, resulting in more reliable production of top-ranking families and sufficient broodstock for commercial spat production. This opportunity could yield reduced effort in the long term. The program could potentially generate genetic gain faster, improve deployment of gain and potentially free up resources for increased research effort (e.g. to understand QX resilience).

The compact larval flow-through systems used by New Zealand breeding programs (see Appendix 3) are highly reliable and cost effective. They consistently produce high spat yields, and double as valuable research tools. Oyster larvae can typically be set and fluidised as spat in a single system, providing further nursery capacity. Additional innovations relating to fertilisation and gamete handling methods may also provide improved reliability.

While we acknowledge the challenges of SRO rearing, alternative family production systems and new hatchery-process knowledge should be evaluated for potential applicability. This will be an associated short-term cost, and resources will need to be found for evaluating process options and subsequent implementation. Methods used by 'local' breeding programs, such as those of ASI and Cawthron, should be explored (ideally through potential collaboration).

Broodstock conditioning is a problem for both the breeding program and hatchery operators. Efforts to increase the supply of broodstock per family will be beneficial, but there is scope to understand the biology and husbandry of condition, share knowledge and again increase breeding power for reduced effort.

Synthesised recommendations:

17. Identify the most significant hatchery bottlenecks and points of loss in the family production process by mapping against international best practice. Cross reference these with the likelihood of finding practical solutions (e.g. improved conditioning may be impactful but difficult, while adopting new systems may help overall reliability and increase success). Budget, resource, and implement the solutions, and leverage research and industry (hatchery) collaborations.

Vision*:* SRO breeders identify the best families for breeding. These are brought in for conditioning, which is a reliable process that yields 80% spawning oysters. Optimal matings, most planned previously, are made over 2 days. Following this, 90% of fertilisations are successfully transferred to larval rearing, and 90% of families yield sufficient spat for field trials and broodstock deployment. Research trials in parallel to the family spawning will continue to improve hatchery methods.

6.2 Targeting genetic gain

The current breeding program has historically prioritised QX resistance as a binary trait (survival vs mortality), but evolving perspectives and industry needs now require a broader and more integrated view of resilience. We encountered strong interest in moving beyond survival alone to include general resilience measures such as growth under (e.g. salinity) stress, alongside condition and scope for growth. There was particular reference to developing disease-tolerant oysters that still achieve marketable performance. These opportunities could better align the program with industry needs and help researchers generate targeted research output. Climate change research is particularly relevant to QX, where underlying drivers like low-salinity and higher temperatures are already present and likely increasing issues. Research trials (e.g. salinity tolerance and endurance) could utilise families and provide data for the breeding database. In turn, this will build understanding of relationships between environmental drivers and QX resilience

At present, breeding objectives are not always clearly articulated, and we observed some lack of alignment between the need for simple phenotyping measures and industry expectations. Some stakeholders prioritise growth and market recovery time, while others emphasise condition or robustness to variable growing environments. Without a tighter connectivity between program objectives and industry requirements, there is a risk of delivering suboptimal outcomes or losing stakeholder confidence.

This connectivity needs to flow in both directions. Industry stakeholders need a better understanding of breeding and the breeding program, and they require a clear picture of what they can and can't do. The implications of selection decisions and the role of genetic correlation should be clearly communicated. The breeding program also needs to understand and adapt to industry's changing needs and environment. As an example, Cawthron meets annually with both the Pacific oyster and Greenshell™ mussel industry representatives to review trait relevance and the selection index. These meetings review what has worked well, what has changed and what issues have increased or decreased in importance. To optimise efficiency and productivity, the selection index and breeding objectives are fine-tuned annually to ensure they remain appropriate and relevant while avoiding over-correction.

There are opportunities to refine the breeding process – selection methods, mating design, analysis, etc. – to further improve the rate of genetic gain. Much of the data required for this process already exist, but additional modelling and analysis will be needed to determine the cost–benefit of making these changes. Ensuring the program follows best practice should be the responsibility of the SROBPTC, and all processes and their rationale should be documented in the SRO breeding manual.

Synthesised recommendations:

18. Develop research integration plans for potential projects that unite the breeding program and climate change research. This work should explore the relationships between the traits driving resilience and QX susceptibility, and subsequently develop proxies for family assessment. For example, laboratory-based stress-on-stress assays of spat using low salinity and temperature could be trialled as resilience proxies. Engage industry stakeholders as partners in this mutually beneficial research.
19. Explore potential trial designs to improve the coverage of QX field trials across environments. Having more trials would increase coverage of sporadic QX events (and high rainfall events) to help understand G×E interactions. Consider the use of genotyping for smaller field trials that might be analysed only when environmental challenges occur and these sites become informative.
20. As part of the partnership process, schedule annual meetings to review and fine tune breeding objectives, the selection index and overall program progress. This presents an opportunity for data exchange (e.g. on-farm performance), knowledge exchange (e.g. discussing genetic correlation implications) and co-development.
21. Identify areas of concern or opportunity within the existing breeding pipeline where fine-tuning and or modification of methods may provide more rapid genetic gain. For example, testing the effects of culling and selection methods on selection response for correlated traits, and confirming that an annual measure-and-select cycle for QX survival is preferable to a 2-year cycle yielding more accurate assessment data.
22. Complete and update the SRO breeding manual 'program documentation' to formalise trait and breeding objective decision-making processes. Provide the manual to reviewers at the earliest opportunity in any future review process.

Vision*:* A closely aligned relationship between industry and the breeding program researchers will ensure both have a clear understanding of each group's needs. Regular (e.g. annual) review and update workshops will help the selection processes stay relevant and adaptive. A more developed level of understanding underpins traits like QX resistance, where the field survival metric is backed up by other measures of physiological resilience, such as salinity and temperature tolerance, scope for growth, etc.

6.3 Field trials and family evaluation

We repeatedly heard the conflicting message that more field trials were needed to improve data relevance and cover sporadic environmental variation, but current resources barely covered the existing trials. We suggest several operational and technical changes to resolve these conflicts.

In terms of resourcing, NSW DPIRD researchers currently spend a significant proportion of their time managing trials, 'working' oysters and carrying out assessments. Based on other successful breeding programs, we suggest that most of the on-farm workload should be completed by industry farm staff. These experienced professionals understand best how to grow oysters. Moreover, they are already on location and can provide valuable insight into oyster family performance. Ultimately, they are the stakeholders who will benefit from the program. In our experience, upskilling farm staff to manage on-farm breeding operations is a win-win. They become program ambassadors and are better positioned to feed information back into improving the operational and technical aspects. Farmers provide all on-water services for the New Zealand Pacific oyster and Greenshell™ mussel breeding programs, apart from some supervision and research assistance for complex trait measurement. This demonstrates industry commitment (to external funders) and true partnership – i.e. 'We can't do this without your help'. Industry providers gain a deeper understanding of breeding and the breeding program , and they get to see the outcomes and family performance firsthand. Valuable resources are then made available for research, rather than being used solely for maintaining oysters.

While farmers hosting family trials benefit from hands-on involvement, their critical in-kind contributions to the program operation must also be formally recognised. A component of NSW DPIRD time would still be required for coordination and supervision of trial maintenance and assessment, as well as providing the extension to enable the transfer of workloads.

We expect that the transfer of field trial workload will free up resources and provide options to extend current trials. Our suggestions for expansion include having two sites (redundancy) for the harvest assessment trials and additional sites for QX trials (to capture a wider range of environments and multiple challenges). We also recommend more frequent or targeted assessment of QX survival. These decisions should be made through the NSW DPIRD and industry partnership and be guided by the SROBPTC.

We also suggest that the SROBPTC be empowered to explore technical or research-based options for expanding family evaluation. These options could include: using genomic approaches for smaller mixed-family assess-as-needed trials; developing laboratory-based spat assays (e.g. salinity × temperature) as proxies for field survival (and to better understand factors underlying resilience); and utilising new technologies such as image analysis. Consideration should be given to the potential role of genomic selection and positioning the program to realise the potential of genomic approaches.

Synthesised recommendations:

23. As part of the overall partnership process, transfer responsibility and workload for family trials to industry, with NSW DPIRD support and guidance via extension. Where possible, data entry should be completed by those collecting the data. This process will support industry as the key stakeholders responsible for ensuring the highest-level of work is completed. They also gain the greatest advantage from successful breeding outcomes. Document standard field procedures in the SRO breeding manual.
24. The NSW DPIRD and industry partnership and the SROBPTC should determine additional family trial needs and opportunities, reflecting updated breeding objectives and program goals.
25. The SROBPTC should routinely evaluate new opportunities for improved trial designs and assessment methods that incorporate new technologies.

Vision: Efficient and cost-effective farm trials will ensure that research staff can focus on expanding the program's knowledge base and filling the research gaps. Industry stakeholders will be directly involved in the management of field trials and, as a result, have a much better understanding of how breeding works. They will see the results firsthand and can use this knowledge to guide best practice. More data, and from a wider range of sites, will improve confidence and ensure that the right variables are measured at the right time and in the right place.

6.4 Deployment pipeline

Deployment emerged as a key operational bottleneck; generating *and* deploying genetic gain are equally important. Symptoms of inadequate deployment pipeline were easily identified: insufficient numbers of broodstock, problems with broodstock conditioning, coordination of hatchery production and farm requirements, difficulty tracking stock performance through the supply chain, and difficulty demonstrating on-farm genetic gain.

The review found that hatchery capacity, reliability and confidence in the NSW DPIRD supply chain are fragile. The NSW DPIRD hatchery team is under-resourced for the scale and complexity of the program they are expected to deliver. Simultaneously, commercial hatcheries have limited ability to influence broodstock sourcing.

Trust in the hatchery system also emerged as a bottleneck, as it limited adoption of improved genetics on farm. Instead of considering breeding value, some farmers base their procurement decisions on perceived reliability and performance of spat supplied by specific hatcheries. This indicates a need for clearer attribution of genetic gain and a separation of genetic performance from operational variability.

A certification or traceability process (see the New Zealand radiata pine GF Plus™ system for a working example; Appendix 4) could improve transparency and enable generic merit to be tracked through the hatchery, nursery and farm supply chain. This could provide compliance checking (that people using broodstock have legal access), and it could be used by hatcheries and nurseries to differentiate products based on genetic merit (and justify levy collection for a 'premium' product). Farmers could use the process to establish their own link between genetic merit and on-farm performance – and demonstrate the value proposition more widely. Moreover, transparency of genetic merit will enable the value proposition to become self-apparent. A certification process may also help prevent uncontrolled use of genetic material (and IP). Much of this process could be automated via an online portal.

A simplified implementation of such a system could make use of the existing selection index as a 'QX rating' to indicate predicted performance in QX-challenged regions, and a 'GC rating' (growth and condition) to indicate predicted performance in areas where QX is not a problem (but growth and condition are priorities). Such ratings would be easier to understand and remember from year-to-year compared to multiple EBVs. For example, a hatchery could supply QX10 / GC5 spat for a QX-challenged region and QX5 / GC15 spat for a non-QX region.

The lack of demonstrated genetic gain is a key trust barrier; lack of evidence means farmers must rely on a faith-based approach to breeding. Overcoming this barrier is urgent and important if widespread uptake and program support is the goal. In the New Zealand shellfish industry, having early leaders in the field 'discover' the benefits of breeding was a powerful influence, and breeding rapidly shifted from a faith-based concept to a must-have tool for the wider industry.

Improving communication, transparency and role clarity between the breeding program and commercial hatcheries is essential. A reliable hatchery spat supply is critical to full utilisation of the program's genetic potential.

At the same time, some promising innovations are emerging. The recent shift of broodstock holding to commercial farms (e.g. East 33) demonstrates the potential for shared responsibility, better conditioning and more flexible timing. While this shift requires robust protocols, good biosecurity management and transparent reporting, we reinforce that it is the best way forward. Industry stakeholders are well placed to manage stock on their farms, and it is important to recognise the value of this contribution. Significantly, this change also potentially redirects the focus of NSW DPIRD resources to research and 'what *they* do best'.

Synthesised recommendations:

26. Improve family production to yield sufficient numbers of broodstock for all families, and improve conditioning protocols for reliable spat production. Revise broodstock supply conditions to allow hatcheries improved freedom-to-operate.
27. Complete the shift to industry-led broodstock management. NSW DPIRD should maintain the nucleus broodstock, but industry could hold all deployment stock under agreed protocols for commercial hatchery use. Additional cost recovery among industry members may be needed to offset broodstock management workload, or a cooperative model could be used. Any form of effort should be recognised in the overall industry contribution to the program.
28. Implement a transparent system for tracking genetic merit, potentially linked to levy and IP management.

Vision*:* NSW DPIRD should focus on running the core breeding program and generating new research knowledge. This work will enable the program to grow and strengthen, adapting to changes in the environment and industry needs. Industry should be responsible for ensuring the program's gains are successfully deployed to the farm via well-coordinated broodstock management and hatchery operations. A new spat certification system could provide information flow from hatchery to farm, ensuring farmers identify the genetic merit of their spat and can relay performance of these stocks back to the breeding program. This knowledge can also be used to market the program more widely. Farmers will be confident that they can obtain spat when needed and that it will have the required level of improvement and known performance. Hatcheries will have established a secure and profitable position in the supply chain as a critical component in the success of breeding program.

6.5 Governance, structural reform, partnership and additionality

A persistent finding across previous reviews and multiple stakeholder interviews is the fragmentation of responsibility and the diffusion of leadership within the SRO Breeding Program ecosystem. While NSW DPIRD has delivered the foundational science, industry input and confidence in governance have remained limited. Governance structures have evolved slowly and often without sufficient transparency or shared ownership, contributing to recurring issues in implementation, communication and the management of expectations. SOCo was raised as an example of 'what not to do'.

A body or entity is needed that represents both the NSW DPIRD and industry. An effective working partnership will support timely decisions, leverage funding and build trust. This body should have a global view of the breeding program, with DPIRD, hatcheries, farmers, funders and regulators all seen as critical components needed for success. Mechanisms to ensure scientific integrity, transparency of performance data, co-design and mutual accountability will be needed. The partnership will need to clearly define what resources (cash and in-kind) will be deployed, and under what targets and controls. Operational targets should also be transparent, including clarity on routine monitoring and reporting to government and industry. The new structure also needs to give members of the 'ecosystem' (Figure 7) the freedom to control their own pathways where appropriate.

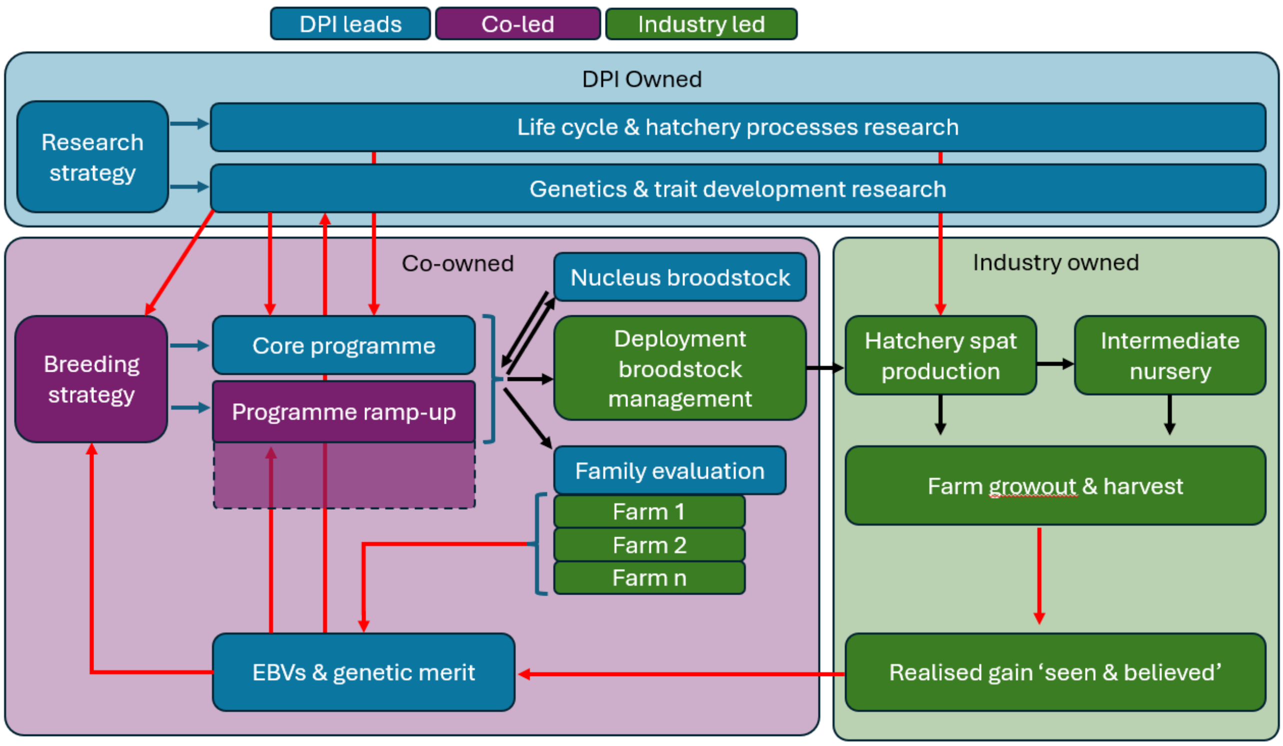

Figure 7. Example of the 'desired state': a cooperative 'breeding program ecosystem' showing critical flows of biological material (black arrows) and knowledge / information (red arrows).

A shared NSW DPIRD–industry governance model emerged from our discussions as the most achievable option, with a clear delineation of roles between science, delivery and implementation. NSW Farmers' Association was identified as a possible industry representative body. Such a structure would allow the industry body to lead stakeholder engagement and decision-making, with NSW DPIRD focusing on genetic evaluation, program design and technical delivery. Industry's aspirations align well with NSW DPIRD's recently launched aquaculture roadmap. This commonality provides an ideal point of engagement and could form the basis of a shared vision for a future partnership. We strongly recommend co-development of the implementation steps underpinning the roadmap with industry via a future partnership.

The punnet matrix below (Table 8) outlines the reciprocal commitments (costs) and benefits that could help shift the program from a compliance-driven structure to one built on shared ownership and strategic co-investment. This enables an 'additionality' model where industry contributions (financial or in-kind) can drive identification or implementation of (new) traits that have commercial value, accelerate cycle gain and improve hatchery feedback loops, rather than being perceived as only a cost-recovery mechanism.

Table 8. Benefit–responsibility matrix: NSW DPIRD and industry-partnership commitments and outcomes.

Commitments	Benefit to NSW DPIRD	Benefit to industry	Benefit to program
NSW DPIRD: • **Co-governance and co-design** • **Release control over downstream delivery**	Reduces political risk & blame Gains trust & shared direction Unlocks capacity to focus on science	Gains transparency and influence Can align outputs with farm needs Greater confidence in value of levy	Governance legitimacy Better trait prioritisation & implementation Greater efficiency & trust system-wide
Industry: • **Formalised support** • **Co-investment** • **Manages broodstock and family assessments**	Unlocks industry co-funding Increases downstream relevance More robust pipeline for EBVs & trials	Faster genetic gain Tailored implementation 'Skin in the game' & ownership	Capacity uplift Shared accountability Practical delivery of breeding value on farm

Without structural reform, attempts to address other recommendations in this report are likely to fall short. **We regard governance renewal as an enabling condition for accelerating genetic gain, reinvigorating the breeding strategy and building industry confidence.**

Synthesised recommendations:

29. Establish an NSW DPIRD–industry (e.g. NSW Farmers' Association) joint governance partnership for strategic oversight and communication. Initiate the process with a memorandum of understanding and simple partnership principles.

30. Formalise role clarity around supporting research (NSW DPIRD), commercial deployment (industry) and program management.
31. Use partnership agreements to define and support areas and opportunities for co-investment and additionality (e.g. resilience trait development), and to identify opportunities to leverage external funding.
32. Encourage transparency through agreed reporting metrics, shared timelines and open performance reviews.

Vision: Future decisions about the breeding program and its operation will be made in partnership and in the best interests of the overall program. Workload, capabilities and accountabilities will be redistributed to where they best align, yielding greater efficiency, ownership and a more effective breeding program. Government will witness a strong value proposition for further investment.

7. Conclusions

This review confirmed many of the initial 'assumptions' identified by the authors, including positive and negative aspects of the current program, and desired attributes of the future program.

Many aspects of the program are working well. The program is producing about 50 families per year, demonstrating that useful genetic gain can be achieved (including for QX). There is strong industry pull for breeding program outcomes and a universal desire to build a successful and respected program. The NSW DPIRD team are genuinely dedicated to doing their best for industry.

The review also identified aspects of the program that are not working well: the level of effort required per deployable family (and genetic gain lost through attrition), the tenuous deployment supply chain, the lack of clearly demonstrated value proposition, and the overall culture of diffuse responsibility, blaming and lack of trust. Many of these problems (and their solutions) are interconnected: family production challenges constrain genetic options and lead to insufficient commercial broodstock for hatcheries; the lack of a compelling value proposition impacts program funding while governance issues hinder implementation of solutions to these, and other, challenges.

A 'better' future program is one where everyone is united and following a best-practice core program that produces optimal genetic outcomes for all. The wider breeding program requires an integrated lab-to-farm supply chain. The benefits of breeding need to be made apparent to industry to encourage widespread participation and enable a sustainable funding stream.

Maintaining the 'status quo' is not a sustainable option. Without decisive transformation, the breeding program faces a slow erosion of trust, capability and relevance. Importantly, government investment will likely diminish, and scientific and operational capacity may be lost or further constrained. Industry confidence will continue to diminish, and with it, the shellfish sector (and state) risks losing one of its most powerful tools for growth, resilience and future readiness.

In contrast, successful implementation of the review recommendations offers a clear and compelling alternative. There is potential to create a sustainable and enduring program partnership – one that reliably delivers commercially relevant genetic gain, accelerates industry growth and positions the sector to respond proactively to emerging challenges. Rather than fixing isolated problems, the focus needs to be on unlocking the full potential of a national asset through shared purpose, co-investment and delivery reform.

The integrated breeding ecosystem proposed is not a redesign but a reconnection of currently fragmented components and a rebuilding of recognised communication paths. The suggested new approach emphasises the reallocation of responsibility and effort to align the stakeholders best positioned to provide, resource and manage the breeding program.

8. Recommendations and implementation plan

Table 9: Key recommendations and suggested implementation plan (sorted by decreasing priority / urgency). Parties responsible for implementing these recommendations should also consider the synthesised recommendations and responses detailed elsewhere in the report.

No.	Key recommendation	Suggested actions (with indicative completion times)	Priority
2	**Family production:** Scope and implement opportunities to utilise next-generation family production methods. There are several low-risk collaboration options that could evaluate the suitability of these methods for SRO.	NSW DPIRD researchers to develop a program of work (< 6 months) to identify and evaluate potential hatchery-process improvement opportunities (12–18 months). This could include working with commercial hatcheries and other breeding programs (e.g. ASI, Cawthron) to identify and test potential improvement opportunities. Leverage existing collaborations. External funding may be needed, especially for implementation of any selected improvements (12–24 months).	High / Urgent
3	**Breeding goals:** Leverage the SROBPTC and SROBPAG to annually review high-level program progress, confirm selection indices are appropriate, identify directions for research that will underpin the future success of the program and update the SRO breeding manual.	SROBPTC to formally schedule annual program review meetings that may include SROBPAG and others (< 6 months). The structure and composition of this steering group may change or be reconfigured as or when a new governance partnership evolves.	High / Urgent
5	**Breeding goals:** Empower industry to play a greater role in guiding the technical direction of the program through co-developed technical publications, breeding workshops and extension.	Leverage SROBPTC and SROBPAG meetings for their knowledge-sharing opportunities (< 6 months). NSW DPIRD to consider increased extension activity (with appropriate resourcing; < 12 months). Publish research (e.g. genetic parameters) and increase the availability of breeding program knowledge and tools (< 12 months).	High / Urgent
8	**Deployment:** Recognise that collaboration and cooperation are needed for the program's success. A strong partnership based on trust and recognition of shared goals is essential.	This will be achieved by working together to create an environment based on trust and open communication. The symbolic signing of an NSW DPIRD–industry MOU could be a formal step in this process (< 6 months).	High / Urgent

No.	Key recommendation	Suggested actions (with indicative completion times)	Priority
13	**Governance:** Urgently establish formal a partnership between industry and NSW DPIRD, beginning with an MOU and partnership principles to build common ground. The NSW Farmers' Association was suggested as a potential partner to represent industry (but this is not necessarily the only or best option). The new partnership should be responsible for leading operational decision-making, particularly decisions relating to connectivity along the breeding program supply chain (e.g. DPIRD, hatcheries, nurseries, farmers). There is scope for an 'independent' program manager to provide oversight and coordination across the wider program.	Industry needs to select their own representation and identify their own breeding program needs in a future partnership (< 6 months), noting there is urgency and compromise will be needed. Industry (via their representative entity) and NSW DPIRD should formalise their commitment to work together via an MOU or similar agreement (< 6 months), prior to the potentially slower process of formalising a governing partnership. Based on the previous governance experiences of the SRO Breeding Program, we suggest a smaller governance group will be more agile and able to make decisions more effectively than a larger committee.	High / Urgent
1	**Family production:** Invest in additional research to improve broodstock conditioning protocols, in collaboration with industry hatcheries who also stand to benefit from these improvements. While this research will be challenging, there are significant benefits for both family and commercial production if successful.	NSW DPIRD researchers develop (< 6 months) and implement a program of research to improve broodstock conditioning reliability (2+ years). This should include working with commercial hatcheries and may link to the broader program goals of genetic improvement for condition. External funding may be needed.	High
6	**Field trials:** Transition to a split-role model where oysters are handed to industry for field trials and subsequent assessment (with NSW DPIRD oversight). NSW DPIRD to provide upskilling, breeding program context and extension to ensure trials are executed to the level of robustness need for generating accurate data.	Under the existing governance model, this would be driven by NSW DPIRD in conjunction with the farmers best suited and willing to assist. Under the (preferred) new partnership model, the partnership would negotiate and manage the implementation of industry field trials. DPIRD should play a lead role in setting / documenting the standards and optimal outcomes for field trials (< 6 months). Industry should ensure their in-kind program input is recognised appropriately. Decisions should be based on 'what is best for the program?' Ideally this should be in place within 18 months.	High
9	**Deployment:** Implement the recommended improvements to family production processes to ensure that all families are of sufficient number to be eligible (if selected) for commercial spat production. Industry should confirm the desired target number of broodstock per family needed for reliable	See recommendations 1 and 2. In addition, some scale-up of the nursery phase may be needed to accommodate sufficient spat for use as commercial broodstock (< 24 months).	High

No.	Key recommendation	Suggested actions (with indicative completion times)	Priority
	commercial hatchery production, which may require the ability to strip spawn.		
10	**Deployment:** Complete the transition to full industry management of broodstock, using the appropriate cost-sharing or recovery model (e.g. recognition of in-kind, direct cost recovery). This should include providing redundant repositories to mitigate biosecurity and environmental risks.	Under the existing governance model, this would be driven by NSW DPIRD in conjunction with the farmers best suited and willing to assist, building on the Wallis Lake experience. Under the (preferred) new partnership model, the partnership (including hatcheries) would negotiate and manage the implementation of industry broodstock management. NSW DPIRD should play a lead role in setting / documenting management standards and expectations (< 6 months). Industry should ensure their in-kind program input is recognised appropriately. Decisions should be based on 'what is best for program implementation (e.g. spat supply)?' Ideally this should be in place within 18 months.	High
14	**Governance:** Use the industry / DPIRD partnership to facilitate and enable the implementation of the other review recommendations such as shifting trial and broodstock workload to industry. The partnership should seek, leverage or reallocate funding to implement relevant research-based recommendations. A sound and enduring partnership will give government the confidence to invest in the program as a generator of economic growth and as ready-response insurance against future challenges.	Responsibility for implementing this review's recommendations (and securing additional funding) should shift to the partnership as soon as practicable (< 6 months).	High
4	**Breeding goals:** Establish stronger connections with existing and future research programs that are aligned with the SRO Breeding Program.	NSW DPIRD researchers (and collaborators) to develop an overarching program plan or map that documents synergies and connections between the breeding program and other aligned research planned or underway (< 12 months). This should be endorsed by the SROBPTC and help ensure optimal use of resources (e.g. families, knowledge, funding). The SROBPTC should play a proactive role in identifying, connecting and facilitating future-aligned research opportunities.	Medium

No.	Key recommendation	Suggested actions (with indicative completion times)	Priority
7	**Field trials:** Evaluate new trial designs that could enable more responsive trial assessment and the incorporation of new technologies (e.g. genomics).	NSW DPIRD to evaluate (in collaboration with genetic services providers) options for novel trial designs suited to the stochastic nature of the QX challenge across multiple environments (< 2 years). This could be a postgraduate project in the first instance.	Medium
11	**Deployment:** Implement a system for making genetic merit (e.g. EBVs) accessible and transparent through production from hatchery to farm (see the NZ radiata pine GF Plus™ system as a working example; Appendix 4). This will enable clear demonstration of the breeding program value proposition.	NSW DPIRD or the new industry partnership should clearly identify their need and explore existing models in other industries (< 12 months). Any proposed system needs to work for NSW DPIRD (as the IP 'generator'), hatcheries (as the supply chain intermediary) and the farmers (who will ultimately link genetic merit to on-farm performance and feedback to the breeding program). Implementation (< 24 months) could be via an online platform and could form part of an IP protection and levy audit process (see recommendation 17).	Medium
12	**Deployment:** Provide upskilling, extension and resources to ensure the entire supply chain (i.e. hatcheries, nurseries, farmers) understands the principles of deploying genetically improved stock, interpreting EBVs, trait trade-offs, the impact of culling and within-family selection, etc.	Potentially in conjunction with recommendation 5. Leverage technical committee and SROBPAG meetings for their knowledge-sharing opportunities (< 6 months). NSW DPIRD to consider increased extension activity (with appropriate resourcing, < 12 months). Publish research (e.g. genetic parameters) and increase the availability of breeding program knowledge (< 12 months).	Medium
15	**Governance:** Ensure that the SROBPTC is delegated a more active role in overseeing and reviewing the operation of the nucleus breeding program, including family production, assessment, genetic analysis and new research or tool development (e.g. genomic selection) opportunities.	The current technical committee should schedule regular (at least annual) meetings to review the program's previous 12 months and to look forward with a 5-year horizon. Any new governance partnership should review the committee's terms of reference in line with the review's recommendations (e.g. 3, 4, 5, 12).	Medium
16	**Governance:** Formalise overarching intellectual property (IP) principles including ownership of existing material versus material originating from any new partnership. A spat certification process may help provide confidence that only legitimate users have access to spat from the breeding program (and / or have paid a levy to access it).	NSW DPIRD or the new industry partnership should develop a clear IP and levy-rate position, e.g. for NSW farmers hosting trials / broodstock or NSW farmers generally, for out-of-state farmers, for hatcheries / nurseries. A certification system could form part of the authentication and audit process for managing germplasm IP (see recommendation 11).	Medium

9. Conflict of interest

Dr Rob Banks was previously Director of the Animal Genetics and Breeding Unit (AGBU) in Armidale, Australia. AGBU is a joint venture of NSW DPIRD and the University of New England. Rob is currently an independent director on the board of Australian Seafood Industries Pty Ltd.

Nick King is employed by Cawthron Institute (Cawthron). Cawthron is an independent profit-for-purpose organisation that engages in research collaborations and provides fee-for-service advice in the fields of shellfish hatchery processes and aquaculture breeding. Cawthron collects a small royalty on sales of Cawthron Ultra Density Larval (CUDLS) tanks.

10. Appendices

Appendix 1. Review terms of reference

1. Review current breeding program practices and procedures, such as:
   a) family production (including numbers of families)
   b) family hatchery practices
   c) family field deployments
   d) measurements taken
   e) genetic analyses
   f) data management
   g) management of the overall breeding population
   h) any other procedures directly related to the implementation of the breeding program.
2. Review the current breeding objectives, breeding goals and selections traits with reference to the feedback provided by the various stakeholders.
3. Review the procedures in place for broodstock supply for commercial propagation with reference to the feedback provided by the relevant stakeholders.
4. Engage with NSW DPIRD to determine departmental needs from the breeding program.
5. Engage with the Sydney rock oyster industry representatives to determine commercial and market needs from the breeding program.
6. Engage with key hatchery suppliers to determine commercial and market needs from the breeding program.
7. Review the genetic progress of this breeding program and comment on the success of the program relative to realistic expectations.
8. Advise on changes to the operational structure of the program required to meet the emerging business needs identified above.
9. Advise on the implications of potential changes to selection technology in the operation of the breeding program.
10. Review the scientific understanding and knowledge base that supports the breeding program and identify any knowledge gaps that require research.

Review meetings will be a mixture of face-to-face and online. Background reports and previous research will be made available and reviewed prior to in-person engagement. It is expected that Nick King will travel from New Zealand to New South Wales to familiarise with breeding operations and facilities. This trip will include as much engagement with researchers, end-users and stakeholders as is practical. Additional review meetings will be held online.

A written report and plain English summary addressing the above criteria will be drafted. The report will be finalised and presented to the NSW DPIRD and SROBPTC.

Appendix 2. Reviewers' biographies

Rob Banks and Nick King were identified as providing the best set of complementary skills and experience to inform this review process. Rob is highly respected in both industry and academic environments, while Nick has several decades of experience in generation and deployment of genetic gain in research and commercial settings. Nick is supported by Cawthron Institute's aquaculture and breeding scientists. Staff from NSW DPIRD and CSIRO will be consulted for technical background and related program insights.

Dr Robert Banks is a PhD graduate of UNE, with a career in research and development (R&D) for the genetic improvement of Australia's extensive livestock industries. Rob worked for Meat and Livestock Australia for nearly 25 years, initially establishing the genetic evaluation system for the Australian lamb industry, LAMBPLAN. He then led the process of extending LAMBPLAN to provide genetic evaluation for the merino industry. More recently, and in response to rapid advances in genomic technologies over the last 5 years, Rob led the development of Information Nucleus flocks and herds, laying the foundations for implementation of genomic selection. Rob's role in Meat and Livestock Australia was extended to include management of R&D investments across the full spectrum of pasture improvement, grazing systems, climate change adaptation and genetic improvement. In 2013–21, Rob had the role of Director of the Animal Genetics and Breeding Unit (AGBU) in Armidale. AGBU delivers R&D and delivery to a range of industries, and while Rob was Director, AGBU developed and delivered single step genomic evaluations for the beef and sheep industries. They also conducted R&D in a range of species including dairy sheep and goats, prawns, canola and honeybees.

Mr Nick King is an aquaculture scientist at Cawthron specialising in shellfish biology, breeding and aquaculture production. He has experience in both research and commercial environments across a wide range of disciplines, including shellfish biology, genetic improvement, hatchery systems and data management. His role ranges from technical support through to research program design, genetic evaluation and research strategy. Nick has led and co-led nationally significant programs relating to aquaculture production and breeding such as The Cultured Shellfish Programme and subsequent Shellfish Aquaculture Platform. Nick's commercial R&D experience includes growing and optimising the supply of genetically improved *Pinus radiata* seed from the New Zealand radiata pine breeding program in the 1990s. At Cawthron, he was instrumental in establishing breeding strategies and commercial breeding programs for the New Zealand Greenshell™ mussel and Pacific oyster industries. He also helped design hatchery infrastructure and protocols for both breeding program execution and commercial-scale deployment. As a result, Cawthron is now a key supplier of Pacific oyster spat and breeding services to the New Zealand oyster industry. Cawthron enabled the hatchery capability, breeding program and triploid induction resources that now supply over 40% of New Zealand Pacific oyster production. Cawthron is also a shareholder in BreedCo, the Greenshell™ mussel breeding program operated by Sanford / SPATnz, New Zealand's largest producer of Greenshell™ mussels.

Appendix 3. Cawthron breeding programs and hatchery systems

This following supplementary material outlines Cawthron's breeding experiences, which may prove useful in the SRO context or as background information.

A3.1 Success factors for shellfish breeding program implementation in New Zealand

The following abstract was presented at ISGA 2022, Chile, and summarises Cawthron's breeding program philosophy, which may be relevant as a case study.

> Despite significant investment in aquaculture genetics and genetic technologies over the last 20 years, the 'development of well-managed and long-term selection programmes' continues to be identified as a critical need to 'significantly expand the global impact of genetic improvement on aquaculture production' (FAO 2019). Cawthron initiated shellfish breeding programmes for the Pacific oyster Crassostrea gigas (in 1999) and the Greenshell™ mussel Perna canaliculus (in 2002). The Pacific oyster programme now accounts for approximately 40% of New Zealand's oyster production while the mussel programme is on-track to represent 30% of that industry's production. We are often asked what factors enabled the successful implementation of these programmes; here we identify some of these. From the beginning, we took a pipeline approach developing methods for breeding at scale, identifying the potential for genetic improvement in traits of commercial interest (i.e. determining heritabilities and genetic correlations), and working with industry to implement breeding at 'industrial' scale. Partnerships with industry (e.g. identifying breeding goals, provision of on-water broodstock holding and grow-out trials, implementation) and government (e.g. research funding and implementation support) were critical. Complementary research and investment helped industry build the necessary hatchery capacity to enable deployment of genetic gain. Demonstration of genetic gain has provided the final element to generate wider industry demand for selectively bred hatchery spat.

A3.2 Implementation timelines

The timelines for program implementation for both the Pacific oyster and Greenshell™ mussel are shown below (Figures A3.2.1 and A3.2.2).

In summary, the period 1999–08 was largely characterised by development of breeding tools and methods (family production, building partnerships and demonstrating proof of concept, including potential breeding gains). Government funding supported all laboratory-based aspects of the program, while industry co-funded all on-water operations.

The period 2008–15 bedded in the routine breeding operations while extending government-funded research (which was The Cultured Shellfish Programme at that time) to extend the core breeding work. This included research using breeding program families to explore energy budgets, shellfish resilience and triploid induction. Most research leveraged families to provide consistent raw material for trials as well as the option of divergently selected families (e.g. selected for high and low thermal tolerance). Any genetic parameters estimated from this research in turn informed the breeding program. Key hatchery bottlenecks were addressed prior to commercial scale-up.

From 2015, significant investment in hatchery capacity enabled industry commercialisation, and Cawthron's breeding program role shifted to that of a service provider. This enabled Cawthron to further reprioritise its research effort toward genetics and shellfish health (rather than breeding program operation).

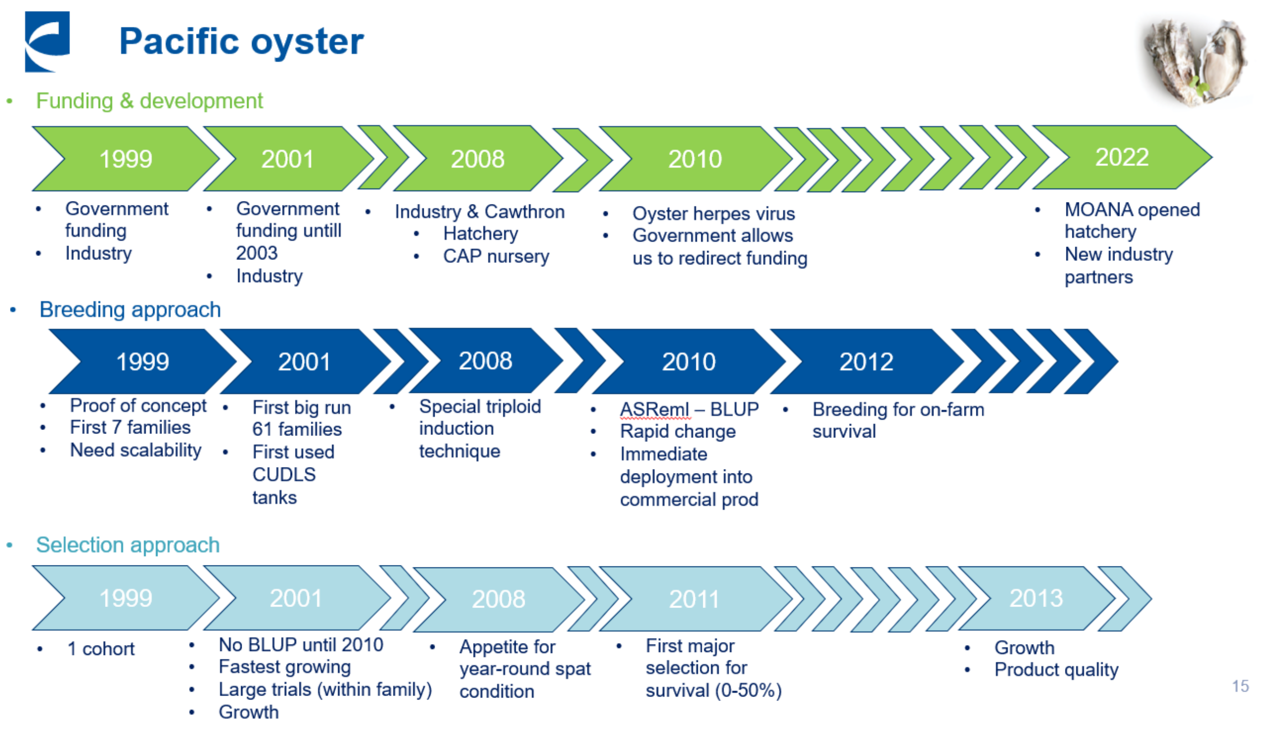

Figure A3.2.1. Pacific oyster breeding program implementation timeline. Source: Megan Scholtens, Cawthron.

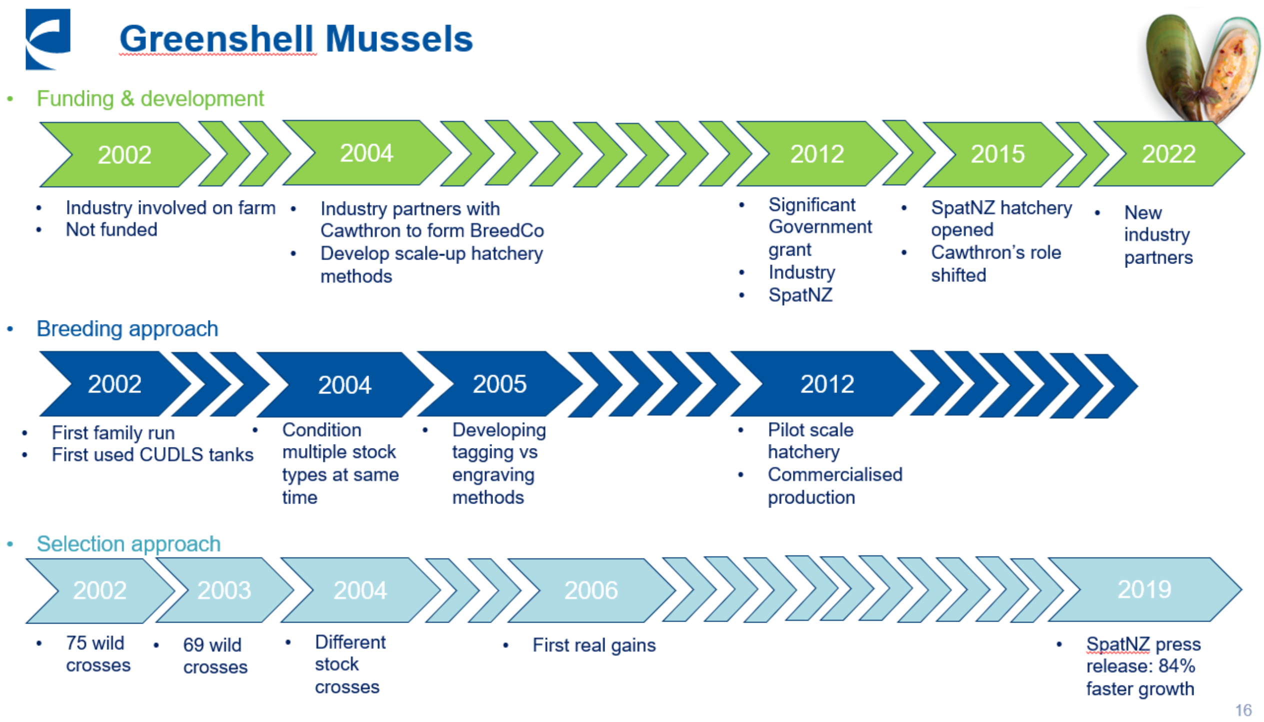

Figure A3.2.2. Greenshell™ mussel breeding program implementation timeline. Source: Megan Scholtens, Cawthron.

A3.3 Family rearing processes

Figure A3.3.1. Cawthron Ultra Density Larval System (CUDLS) set up for 72 families. This rack has 144 tank positions to allow for simultaneous larval rearing and spat setting or fluidising.

Cawthron Ultra Density Larval Systems (CUDLS; Figure A3.3.1) have produced more than 1,500 bivalve families since 2001. Typically, over 95% of incubated families are successfully reared with sufficient spat numbers for evaluation and commercial spat production. Basic principles of operation are published in Ragg et al. (2010) for Greenshell™ mussels and Vignier et al. (2025) for Pacific oysters. The 2.5L tanks generally exchange between 40 ml/min and 80 ml/min of 1 um filtered seawater while providing an outflow microalgal concentration of 20–40 cells/ul depending on the shellfish species. For a given number of larvae, the CUDLS typically needs half the water requirement of a static system. Two technicians can typically manage the daily screening and cleaning requirement for a 60-family cohort.

Appendix 4. GF Plus™ system in New Zealand radiata pine breeding

A Seed Certification Scheme was introduced in 1987 as a mechanism for connecting the outputs of the radiata pine breeding program with the market. The original growth and form (GF) index provided a simple and widely recognised rating of expected performance based on genetic merit.

In 1988, the Forest Service-owned breeding program transitioned to an industry-partnership model, the New Zealand Radiata Pine Breeding Cooperative, with combined industry and government funding support.

In 1998, just prior to the New Zealand Radiata Pine Breeding Cooperative becoming the Radiata Pine Breeding Company, the GF Plus™ system[1] was introduced. This system quantifies genetic merit for individual traits based on their EBVs, including growth, wood density, straightness and disease (*Dothistroma*) resistance. The Seed Certification Service provides certificates to seed orchard managers and to nurseries on purchase of seed. All purchasers of nursery stock are entitled to receive a seed certificate certifying its genetic composition and merit.

Benefits of this system include:

- Ratings can be used to select seed, seedlings and cuttings with higher values for traits favouring a forest grower's end-product objectives.
- Ratings provide a basis for value-added pricing and royalty collection.
- The certification process provides an independent audit trail for seed sales and purchases.
- Growers can independently determine the relationship between genetic merit and crop performance.

[1] https://www.rpbc.co.nz/pages/gf-plus-tm

Appendix 5. Benefit–cost analysis

Mike Dove's (pers. comm.) benefit–cost analysis (BCA) based on 2015 figures provides a sound basis for understanding the economic impacts and returns from the SRO Breeding Program.

Three benefits are identified:

- Reduced time to market, based on one less year – $2.9 M per year
- Return to production for QX-affected estuaries – $3.2 M per year
- Reduced losses from winter mortality – $0.9 M per year

Costs were identified as:

- CRC development project cost – $306 k
- Annual breeding program cost – $250 k

Together these generate:

- BCR (benefit–cost ratio) = 7.0:1
- IRR% (internal rate of return) = 36%
- NPV (net present value) = $6.9 M

The logic set out in the benefit–cost modelling is sound, noting that the cash flow predictions allow for slow growth in market share for SRO oysters. It should also be noted that the modelling used 2015 prices and costs. Given that the returns from genetic improvement are cumulative, and costs are linear (i.e. a relatively fixed amount per year), increases in income (i.e. via price rises) are likely to have a larger effect on the income line than the cost line, in terms of overall return on investment.

At the same time, the model incorporates returns from seed sales, which from a whole-of-industry perspective are simply a component of overall cost of production. Also, costs of research are assumed fixed in nominal terms. Together, these effects could be re-examined, but the overall message is unlikely to be dramatically altered.

An alternative is to assume a total industry sales value of $50 M per year and assume that a 1% improvement per year is achieved via genetic gain. That equates to a benefit of $0.5 M per year, or $27.5 M (undiscounted) over 10 years. The ongoing cost is about $0.5 M per year or $5 M over 10 years, giving a basic BCR of 5.5:1.

Noting that Mike Dove's estimate is more rigorous, the message is clear that even with conservative modelling of benefits and costs, the investment in the industry breeding program is very likely to be highly attractive (Note that the return is likely to have been positive even with the production losses of some years).

There is value in considering the benefits in terms of the extent to which they are public or private, or a combination:

- Reduced cost of production, and any increase in price per dozen through shape, condition, etc, seem predominantly a private benefit.
- Reduced risk of loss of production through the mortality causes seems reasonable to describe as at least partly a community benefit – essentially by maintaining a resource that could not otherwise be used.

Using Dove’s values, and this suggested split, the private:public benefit ratio is close to 3:4. This supports the value of a shared investment whole-of-industry model – especially when factoring in the need for ongoing R&D.

Appendix 6. Individuals and groups consulted

- Emma Wilkie (NSW DPIRD)
- Laura Parker (NSW DPIRD)
- Peter Kube (formerly CSIRO)
- Ian Duthie (SeaPerfect; Director, Oysters Tasmania and Oysters Australia)
- Greg Kent (NSW DPIRD; formerly Southern Cross Shellfish)
- Mike Dove (NSW DPIRD)
- Ian Lyall (NSW DPIRD)
- John Stubbs (formerly Hawkesbury River farmer)
- Adam (Hawkesbury River farmer)
- Matt Toan (East 33)
- Ben (East 33)
- Brandon Armstrong (Armstrong Oysters; Chair, NSW Farmers' Association Oyster Committee)
- Steve O'Connor (NSW DPIRD)
- Wayne O'Connor (NSW DPIRD)
- Igor Pirozzi (NSW DPIRD)
- Gary Zippel (oyster farmer; Director, Oysters Australia)
- Sydney Rock Oyster Breeding Program Advisory Group (SROBPAG)
- Chris Gilles (SeaGen Aquaculture)
- Curtis Lind (CSIRO)
- Adrian Pinkerton (Merimbula farmer)
- Len Stephens (formerly Chair, Oysters Australia)
- Tony Troupe (hatchery producer)

11. References

Bunter K. 2007. Technical evaluation of the SRO Breeding Programme. Report prepared for milestones four and five of the FRDC Project 2005/209.

Davis J, Lewis T. 2019. Review of the resourcing of an industry focussed breeding program to ensure the continual and proactive development of superior Sydney rock oyster genetics, and industry input to breeding goals and access to the breeding program outputs. Report prepared for the NSW Shellfish Committee.

Dove M, Kube P, Lind C, Cumbo V, Raftos D, O'Connor W. 2020. Accelerated Sydney rock oyster (SRO) breeding research. Report prepared for FRDC project 2016/802.

Dove M, Kube P, O'Connor S, Lind C, Johnston K, Archer B, O'Connor W. 2021. The Sydney rock oyster family based breeding program manual. Standard operations manual for the DPIRD programme.

Lind C. 2025a. DPI Sydney rock oyster SBP, individual performance, 2025 EBV Run#1. CSIRO data analysis summary for NSW DPIRD.

Lind C. 2025b. SRO EBV Run 2, QX trials – Year class 2023 & 2024 with repeat measures. CSIRO data analysis summary for NSW DPIRD.

O'Connor WA, Dove MC, Thompson EL, Parker LM, Ross PM, Raftos DA. 2014. Breeding Sydney rock oysters and its effects on resilience. https://www.cabidigitallibrary.org/doi/pdf/10.5555/20203123708

Ragg NLC, King N, Watts E, Morrish J. 2010. Optimising the delivery of the key dietary diatom *Chaetoceros calcitrans* to intensively cultured Greenshell™ mussel larvae, *Perna canaliculus*. Aquaculture. 306:270–280.

Rye M. 2012. Review of Australian breeding programs for Pacific oysters, Sydney rock oysters, barramundi and prawns. Report prepared for Australian Seafood CRC.

Schrobback P, Pascoe S, Coglan L. 2014. History, status and future of Australia's native Sydney rock oyster industry. Aquatic Living Resources. 27(3–4):153–165.

Tynan R, Bunter K, O'Connor W. 2010. Industry management and commercialisation of the Sydney Rock Oyster Breeding Program. Report (no. 124) prepared for Australian Seafood CRC (project 2005/209).

Vignier J, Reardon M, Exton M, Delisle L, Rolton A, Malpot E, Scholtens M, Welford M, Zamora L, Delorme N, Dunphy B. 2025. Comparative performance of selected triploid oysters *Crassostrea* (*Magallana*) *gigas*, produced by chemical induction and mated triploid techniques, to their diploid counterparts. Aquaculture. 596:741894.

[NSW DPIRD] New South Wales Department of Primary Industry and Regional Development. 2024. Sydney Rock Oyster Breeding Program update. https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/1548052/Sydney-Rock-Oyster-Breeding-Program-Update-April-2024.pdf

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