Education and training exchange program with Nofima, a world leading aquaculture research institute

Nick Robinson

Project No. 2008/772

AUSTRALIAN SEAFOOD COOPERATIVE RESEARCH CENTRE

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This project was conducted by Flinders University, Sturt Road, Bedford Park, SA 5042, Australia and Nofima, PO Box 5010, 1432 Ås, Norway

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Non-Technical Summary

2008/772 Education and training exchange program with Nofima, a world leading aquaculture research institute

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PROJECT OBJECTIVES:

1. To give owners, managers, geneticists and hatchery staff involved with selective breeding programs in Australia short-term exposure to facilitate the establishment of dialogue, cooperation and/or collaboration with international players on the selective breeding scene
2. To directly educate and inform scientists making decisions about selection and mating (at least one person for each aquaculture industry participating in the Seafood CRC) and those involved with the day-to-day operation of the nucleus or hatchery about the latest technical developments overseas and how these might be adapted within Australia
3. To improve basic knowledge about establishing, running and profiting from selective breeding leading to implementation of significant and recognisable improvements in breeding programs towards world's best practice (on average at least one improvement per sector)

OUTCOMES ACHIEVED

Here we summarise the outcomes achieved by the project against each of the project objectives.

1 **Internationally recognised selective breeding experts (Bjarne Gjerde, Kari Kolstad, Morten Rye and Bjorn Skjævestad) have participated in workshops, meetings and/or lectures and all levels of industry have participated and benefited. In some cases, these discussions have facilitated major changes or shifts by the industry (including changed business models). Mini-workshops have also been held in Norway with Australian scientists from CSIRO, SalTas, Nofima and AFGC staff.**

2 **The latest technical developments from overseas have been communicated to scientists and hatchery staff through lectures, workshops, webinars and one-on-one meetings. In some cases (near infrared spectrometry, genotyping by sequencing and genomic selection) these technologies are now being utilised to facilitate selective breeding in Australia.**

3a **The oyster sector (ASI, pacific oysters and Sydney Rock oysters) have changed their business model for selective breeding. Barramundi farmers have recognised that a selective breeding program cannot be carried out across numerous individual farms and the business case for**

selective breeding has been supported by our visiting expert. Scientists in Australia have formed connections and collaborations with leading international researchers on selective breeding overseas. New abalone and barramundi breeding initiatives have begun. Salmon selective breeding managers, industry leaders and company representatives have visited Norway, formed links with breeding companies overseas and learnt of the latest business models and technical developments. The prawn industry has recognised that exchange of material needs to occur between the three farms currently undertaking breeding activity.

3b An online genetics course for hatchery managers and other interested participants of the Seafood CRC has been produced by Nofima and is available for members of the industry to participate. The outcome will be improved knowledge skills and application of basic genetic principles to hatchery management.

In summary:

The project has had large participation and interest from both industry and researchers. It has exposed many working with selective breeding programs in Australia to the latest technical developments, experience and knowledge of those who have been researching, developing and profiting from selective breeding programs internationally over the last 30 years. The contacts made through this project have already generated many spin-off research project collaborations and fresh ideas for the participants in Australia. Researchers in Australia have participated in a quantitative genetics and selective breeding workshop with two highly regarded senior scientists from Nofima, Dr Bjarne Gjerde and Dr Kari Kolstad, and have participated in meetings with Nofima staff in Norway. Industry representatives have travelled and held meetings with companies in Norway involved in selective breeding and fish nutrition, and have also met and discussed research opportunities and the latest scientific developments with the staff of Nofima. Dr Morten Rye, Managing Director of the Akvaforsk Genetics Centre has held discussions with industry and researchers involved in the establishment and commercialization of selective breeding programs for fish, molluscs and crustaceans in Australia. Dr Rye's report has reviewed the status of selective breeding programs for oyster, Barramundi and prawn industries in Australia and provides recommendations for commercialization of selective breeding programs and genetic service provision for these industries. CSIRO established a new project which scoped up a commercial genetic service entity for the Australian seafood industries. As part of this, there was a new application for a legacy project that sought to establish a commercial selective breeding genetic service entity in Australia. This action by CSIRO was partly stimulated by Dr Rye's visit. A course (series of webinars) for hatchery staff, managers and hatchery/selective breeding program owners on breeding and genetics has been devised and is being made available for enrolment. Many hatchery/selective breeding managers participated in a special session at the World Aquaculture Society Conference in Adelaide to discuss "How might the business of genetics and breeding unfold". A panel of expert speakers were invited to discuss experiences running selective breeding programs under different business and cooperative type models. New technologies for breeding that were in early phase implementation by aquaculture breeding programs overseas have been picked up and

implemented into selective breeding programs in Australia. The outputs from this project are providing ongoing benefits for the aquaculture industries in Australia (more sustainable businesses supplying seedstock, faster growing more robust stock being farmed and incremental continuous improvement with every new generation of breeding).

LIST OF OUTPUTS PRODUCED

- Visiting experts from Norway have disseminated knowledge from their experiences developing aquaculture selective breeding programs around the world
- Representatives from Industry and Research Organisations in Australia have visited experts in Norway, gained knowledge and made contacts that have helped transform existing practices in Australia.
- A basic education program for hatchery staff, managers and hatchery/selective breeding owners has been devised (webinar) and is being made available for enrolment.

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1. Introduction and Background

A number of businesses are being established in Australia with a primary focus on genetic improvement and the sale of genetically improved stock for aquaculture. The production of selectively bred stock has been shown to have high benefit-cost, even for relatively small aquaculture industries. Selective breeding is highly technical so that even the hands-on running of a breeding nucleus requires a high degree of specialist training. The business of selective breeding is relatively new in Australia and there is much to be learnt from experiences overseas.

Selective breeding is not new on the international scene. In most of the well-known international examples (eg. Atlantic salmon and rainbow trout in Norway) the initiation of these breeding programs occurred while the aquaculture industry was relatively immature. In these cases, government funding was used to initiate the breeding programs and commercial breeding businesses developed later using this same selected stock. In some cases, now, these industries have developed into billion-dollar aquaculture export industries, and the selective breeding program has been seen as one of, if not the most important factor, stimulating and enabling development of these industries. In such cases, the business and science of selective breeding has matured along with the industry. Knowledge gained from these "mature" industries has been used to begin commercial selective breeding programs for newly developed aquaculture industries such as Atlantic cod, cleaner fish etc.

Australian breeders could learn a lot from the experience of Norwegian breeding companies, and from the experience of Nofima (formerly Akvaforsk) who have been providing genetic and breeding research services directly to breeding programs around the world for more than 30 years and who have established programs for Atlantic salmon, rainbow trout, Atlantic cod, tilapia and other species that are now commercialised and recognised internationally. Nofima is widely recognized as a world leader in this research area. Nofima has a strong network of contacts and links with industry that could also be utilised in the education and exchange program.

1.1 Need

Individuals/organisations that would benefit from the program with Nofima are those that are:

1. considering starting selective breeding programs or supplying industry with hatchery stock (as many as 10 industry associations or groups of farms)
2. analysing data and making decisions about the selection and mating of selectively bred stock (as many as 10 genetics service providers, private or public)
3. involved with the day-to-day operation of a nucleus or hatchery (includes many hatchery managers)
4. trying to run a profitable selective breeding or hatchery business (eg. managers or owners of companies such as Australian Seafood Industries PL for Pacific Oyster or Saltas PL for Atlantic Salmon)

Individuals/organisations in these interest groups have overlapping needs to some degree:

A. Need for owners, managers, geneticists and hatchery staff in Australia to be put in touch (network) with those having similar responsibilities in other

sectors within Australia, as well as with international players in the selective breeding scene, so that they can benefit from the experience of existing research organisations and businesses.

B. Australia's reputation, isolation and environment could make it an attractive source of selectively bred stock internationally. Therefore, there is an opportunity for some breeding programs to supply overseas producers with genetically improved stock. But there is a need to understand how such a business might operate and how risks can be managed.
C. Need for those analysing data and making decisions about the selection and mating of selectively bred stock, and involved with the day-to-day operation of a nucleus or hatchery, to be informed of the latest technical developments overseas and how developments might be adopted to benefit Australian breeding companies and aquaculture industries.
D. Need for improving basic knowledge about establishing, running and profiting from selective breeding.

1.2 Objectives

1 To give owners, managers, geneticists and hatchery staff involved with selective breeding programs in Australia short-term exposure to facilitate the establishment of dialogue, cooperation and/or collaboration with international players on the selective breeding scene

2 To directly educate and inform scientists making decisions about selection and mating (at least one person for each aquaculture industry participating in the Seafood CRC) and those involved with the day-to-day operation of the nucleus or hatchery about the latest technical developments overseas and how these might be adapted within Australia

3 To improve basic knowledge about establishing, running and profiting from selective breeding leading to implementation of significant and recognisable improvements in breeding programs towards world's best practice (on average at least one improvement per sector)

2. Methods

2.1 Identify industry needs and develop a structured program supported by key stakeholders.

The PI and other stakeholders in the Breeding for Profit Theme consulted with industry representatives and associations to identify specific needs for training and exchange. For some industries (abalone, temperate marine finfish and barramundi) these needs were already being identified through existing selective breeding scoping studies. The detailed programs (outlined below) were planned in discussion with NOFIMA and selective breeding company contacts in Norway. The planning was achieved using teleconferences, email exchange and a face-to-face meeting with Nofima and company representatives in Norway in August 2009.

2.2 Workshops, industry master classes and bridging programs.

The project supported the visit by Norwegian experts (1 per year) to present at industry workshops and master classes. The workshops and master classes held are described in detail below.

2.3 Development and implementation of exchange programs.

Industry exchange programs where managers of selective breeding companies and/or hatchery managers work for a short period with managers in a similar role from the breeding companies operating in Norway were also facilitated. This was planned to partially fulfill needs A, B, C and D. Funds for travel and accommodation expenses were provided by participating companies. Applications were also made for Seafood CRC industry bursaries ($10,000 per person) for this purpose. Other funding opportunities for industry were explored.

Scientist exchange programs where scientists could take a paid sabbatical to work on a project in Norway or vice versa were also planned. This partially fulfilled needs A, C and D. Funds for bench fees, travel and accommodation expenses were provided by participating companies, universities or institutes. At least 2 CRC research travel grants ($10,000 per person) were earmarked by the Seafood CRC for this purpose also. Other funding opportunities for researchers (including the Australian Academy of Science's fund "Forum for European-Australian Science and Technology Cooperation") were explored by researchers for this purpose.

PhD and MSc student exchange programs, where students working on Seafood CRC related projects could do part of their research for their thesis topic in Norway and Australia, were also undertaken. This partially fulfilled needs A, C and D. Funds for bench fees, accommodation and living expenses were provided by existing scholarships and bursaries. Applications were also made to the Seafood CRC (research travel grants, $10,000 per person) for this purpose.

2.4 Evaluation of success- outputs and future opportunities.

Evaluations of the success of the project workshops and activities were made during the course of the project. Efforts were also made to identify future opportunities for collaboration, partnership etc and to connect potential collaborators/partners in Norway and Australia. The evaluations identified good reasons to continue the project beyond 3 years, and so an application for an extension of the project was funded in the third year.

2.5 Performance Indicators.

Participation in workshops, master classes and bridging programs, exchange programs and work placement programs leads to a change of practice such that:

Indicator 1- Application for new collaborative projects with partners in leading aquaculture research institutes overseas
New collaborative research projects are developed by universities, companies and research institutes in Australia with partners in leading aquaculture research institutes overseas. Joint publications and reports are generated to disseminate the knowledge generated through collaborative research. Knowledge generated by collaborative projects is applied to benefit the industry in Australia. The joint publications and publicity about the cooperation leads to the development of further collaborative projects and knowledge.

Indicator 2 - Breeding companies in Australia share information, form alliances and or establish collaborative agreements with breeding companies overseas.
This results in the breeding companies in Australia supplying stock that gives a greater benefit to Australian industries (increasing the efficiency and competitiveness of our industries in Australia and providing a stimulus for expansion and growth of aquaculture in Australia) and to the breeding companies themselves becoming more profitable and sustainable.

Indicator 3 - Breeding is embraced as a business opportunity in its own right in Australia
Breeding companies expand/merge to take up other opportunities (multi-species, international supply etc) which leads to greater efficiencies and a more profitable and sustainable breeding sector. Breeding companies become a significant contributor to the development and maturation of aquaculture industries in Australia and contribute significantly both directly and indirectly to the export revenue earnings from aquaculture activity in Australia. Supply of international markets is done in a way that the Australian product (genetically improved stock) is protected from further replication or on-sale (eg. genetic and/or legal protection), leading to return business for Australia. Australia develops a reputation as a supplier of high tech, high quality, disease- and contaminant-free certified stock for production in Asia, US, South America and Europe.

3. Results & Discussion

3.1 Needs analysis.

In 2009 industry needs were identified (with input from Peter Kube CSIRO and from the hatchery managers workshops) and a program for exchange activities was developed in July 2009 and modified as the project progressed. An MOU for cooperation between Nofima and the Seafood CRC was signed in September 2009.

3.2 Workshops and other events organised by the project.

First event – Workshop on the analysis of quantitative genetic data and design of selective breeding programs for species in aquaculture, 27-28 May 2010

Aim of Workshop **–** The workshop was organised in order to go some way toward meeting the objectives of Australian Seafood CRC project 2008/722 which were:

1. To give owners, managers, geneticists and hatchery staff involved with selective breeding programs in Australia short-term exposure to facilitate the establishment of dialogue, cooperation and/or collaboration with international players on the selective breeding scene
2. To directly educate and inform scientists making decisions about selection and mating (at least one person for each aquaculture industry participating in the Seafood CRC) and those involved with the day-to-day operation of the nucleus or hatchery about the latest technical developments overseas and how these might be adapted within Australia
3. To improve basic knowledge about establishing, running and profiting from selective breeding leading to implementation of significant and recognisable improvements in breeding programs towards world's best practice (on average at least one improvement per sector)

Format of workshop - The workshop was run as 6 sessions (1.5 - 2 hrs each session) over two days (session titles can be found in the attached program). For each theme some participants were asked to present cases, issues and problems. These case studies were intended to stimulate the discussion. The discussion was chaired by Nick Robinson in order to keep the flow of ideas moving and to give everybody present an opportunity to contribute. Some points were "parked" and taken up again in the afternoon sessions (after 3.30). Everyone came prepared to contribute relevant information, approaches that they have tried, and ideas that might contribute to solving the problems. White boards and data projectors were used to show relevant information for discussion.

Visiting experts – Drs Bjarne Gjerde and Kari Kolstad from Nofima were invited and contributed a great deal of information about the approaches and research done in Norway and elsewhere. Dr Gjerde is a Senior Researcher who has over 30 years' experience investigating aquaculture quantitative genetics, and has over 100 peer reviewed publications in the scientific literature. Dr Kolstad is the Research Leader of the Genetics and Breeding Group in Nofima, and not only has an excellent overview of genetic research activities in Norway, but also has many years research experience. Dr Raul Ponzoni, an experienced Senior Researcher from the World Fish Centre also attended and contributed greatly to the discussions. There were plenty of opportunities for participants to follow up and discuss issues further. One of the purposes was for participants to build links with relevant research projects being carried out in Australia or overseas, and to prompt participants to participate in

further activities as part of the Australian Seafood CRC *Nofima exchange program (project 2008/772).*

Target participants - Quantitative Geneticists and others involved with the technical design and/or analysis of selective breeding programs for aquaculture species.

List of participants - Brad Evans, Mike Dove, Wayne OConner (Friday only), Raul Ponzoni, Jane Symonds, Michael Macbeth, Seumas Walker (Friday only), Greg Coman, John Henshall, Sonja Dominik, Nick Elliot, Fiona Hely, Alex Safari, Richard Taylor, Shannon Loughnan, Michael Tate, Graham Mair, Bjarne Gjerde, Kari Kolstad, Peter Kube and Nick Robinson.

Program - Workshop on the analysis of quantitative genetic data and design of selective breeding programs for species in aquaculture

	Thursday 27 May 2010 (Day 1)	**Friday 28 May 2010 (Day 2)**
8.30	Intoductions and welcome	
8.35	**1. Disease/stress resistance/tolerance** *Includes:* -eg1 new methods for analysis of survival data, eg2 multiple infection data, eg3 tolerance vs resistance) *Case studies:* Richard Taylor – Exhaustion/robustness Alex Safari - Oyster bag count survival Peter Kube - Amoebic gill disease Bjarne Gjerde –Salmon lice	**4. Formulating economic weights** *Case studies:* Peter Kube - oysters, Bjarne Gjerde –issues and approaches Raul Ponzoni- Tilapia
	Break	
10.30	**2. Meat quality traits** *Includes:* -eg4 issues with measurement and analysis, -eg5 formulating breeding objectives for carcase quality traits *Case studies:* Kari Kolstad - market surveys, imaging on live breeding candidate Nick Elliot - Tas salmon issues	**5. Breeding strategies for unconventional situations** Includes: - eg6 biological constraints versus needs for genetic improvement, -eg7 donor/recipient contributions to trait values-pearl oysters) – Case studies: Fiona Hely Dealing with unequal parent contributions in breeding programs incorporating communal spawning and DNA parentage systems, Nick Robinson- barramundi
12.30	Lunch	
1.30	**3. EBV estimation using multiple year class pedigree data** *Case studies:* Peter Kube - Tas oysters and salmon, Bjarne Gjerde – Issues being explored in Norway	**6. Effective population size and management of inbreeding in relation to long term sustainability of genetic improvement programs** Case studies: Raul Ponzoni – Issues and approaches Sonja Dominik or John Henshaw –use of simulation

3.30	Take up further discussion over refreshments	
6.00	We will book a table for dinner somewhere in Salamanca for those who wish to join	

Wrap up

- A full evaluation of the success of the workshop is detailed in the "evaluation of project" section below.
- There was overwhelming consensus that we should run the workshop as a regular event. Nick Elliot said that it was good to start on the general topics that we did, but that we should consider more specific topics for the next workshop (or maybe alternate from general to specific topics each meeting).
- There was some interest (Jane Seymor, John Henshaw and others) in focusing on the application of genomic data (SNP chips, modelling with regard to impact on selective breeding etc) for the next workshop.
- Generally, the consensus was that we should keep the group size to around 25 (so that discussion is uninhibited) but that we should consider who to invite depending on the topic.
- Everyone greatly appreciated the input from the visiting experts Kari Kolstad, Bjarne Gjerde and Raul Ponzoni and felt that much was learnt and good relationships begun.
- There was a suggestion that maybe we could focus on more technical areas (eg tagging) at a next workshop.
- We also discussed whether we should involve more people from the breeding companies. Brad Evans remarked that he was unsure about coming to the workshop, and was concerned about how difficult it would be to follow the discussion, but that he found it was not so difficult to follow the discussion, that participation was extremely useful and that the workshop really has stimulated him to follow up more on some issues in his work place and to apply for a bursary to visit the breeding companies in Norway to see how they function and to learn from them.
- One issue with including more representatives from the breeding companies was that the discussion may be more inhibited (ie participants might be reluctant to present "failures") and that the scientists may be less inclined to discuss uncertainties and problems they are facing (which were felt to be very positive benefits derived from the workshop on this occasion).

Second event –Mini workshop on international commercialisation of selective breeding programs and genetic services: Relevance to Australian aquaculture industries. Morten Rye, Norway

Date/time: August 31 2011, 10.00AM –evening (lunch at Måltidets Hus and dinner in Stavanger to be arranged). Day before Fish Breeders Round Table meeting near Stavanger.

Venue: Nofima Måltidets Hus, Richard Johnsensgt 4, NO-4021 Stavanger, Norway

Attendees: Morten Rye Akvaforsk Genetics Centre, Nick Elliot, Peter Kube and Richard Taylor CSIRO, Graham Mair Seafood CRC, Brad Evans SALTAS and Nick Robinson Nofima

Host/ Chair: NR/GM

Background

The Seafood CRC, through its Breeding for Profit research theme is attempting to facilitate the development of aquaculture breeding programs in Australia through funding of specific research projects and through facilitation of greater cooperation between researchers and industry alike. It is supporting the development of new breeding programs in species such as Yellowtail Kingfish and Barramundi and adding value to existing breeding programs in oysters, prawns and potentially Atlantic salmon. The CRC has funds available to promote cooperation through academic exchanges including the Nofima Exchange program run by Nick Robinson which is promoting exchanges between researchers and industry representatives in Australia and Norway. The CRC is also supporting a suite of 'communal research projects' with a focus on generic approaches to genetic data management and training and extension in aquaculture genetics.

Objectives of workshop

To gain a better understanding about international commercialisation of selective breeding and genetic services for aquaculture.

To have an open discussion about selective breeding in Australia and internationally.

To identify training and cooperation activities in relation to the above objectives including exchanges under the Nofima exchange project.

Agenda for workshop

Welcome (NR). Introduction and summary of current situation (GM)

View of international selective breeding scene from AFGC's perspective (MR)

Lunch

Open discussion (All).

Further discussions over dinner and when opportunities arise at the Fish Breeders Round Table

Third event – Review of Australian breeding programs for Pacific oyster, Sydney rock oyster, barramundi and prawns by Dr Morten Rye of the Akvaforsk Genetics Centre Norway.

Dr Morten Rye, who is Managing Director of the Akvaforsk Genetics Centre (AFGC), which is a major international company providing aquaculture genetics services and which has ownership in several international breeding companies, visited Australia in September 2012. The main purpose of Morten's visit was connected with another Seafood CRC project (communal project 2008/769) for the "Review of commercialization approaches" for Australian selective breeding programs. However, part of the expenses for Morten's trip were also funded from this project (2008/772). This is because the visit was also an opportunity to educate industry members and researchers involved with running and providing genetic services for selective breeding programs with the experiences and knowledge gathered by AFGC. So, in this way, Morten's visit addressed two elements of the milestone (industry master class run and communal project implemented).

AFGC is the largest and longest serving company providing genetic services to fish selective breeding programs in the world today. The company works internationally on important fish and crustacean species for world aquaculture production. AFGC also has ownership in some fish selective breeding programs for Atlantic salmon, tilapia and Atlantic cod (the latter company, MarinBreed, was recently shut down due to a downturn in the cod aquaculture industry in Norway). Morten was therefore able to provide valuable insights into the commercialization of selective breeding programs and about models for the provision of genetic services to selective breeding programs during his visit. It was decided that he should meet and talk with industry members involved with selective breeding programs that are, or are near, fully commercialized, and which have particular commercialization issues that need to be addressed (Pacific and Sydney Rock Oysters, prawns and Barramundi). Morten therefore met and held discussions with the following people and industry groups:

Graham Mair and Len Stephens – Seafood CRC
Chris Calogeras, Ken Chapman, Bob Richards, Desiree Allen, Marty Phillips - Australian Barramundi Farmers Association
Justin Forrester – Good Fortune Bay Fisheries
Dean Jerry – James Cook University
Prawn Farmers Association
Nigel Preston, Nick Elliot, Peter Kube - CSIRO
Nick Robinson – Nofima and Flinders University
Wayne O'Conner – NSW Department of Primary Industries
Scott Parkinson- Shellfish Culture
Rachel King – Oysters Australia
Ben Cameron and Melissa Jansen -Cameron of Tasmania
Jane Clout –Kooringal Oysters
Hayden Dyke – Oyster Bay Oysters
Matt Cunningham, Garry Zippel –Australian Seafood Industries (ASI)
AJ and JS Troup – Camden Haven Oyster Supply

Dr Nick Robinson coordinated and booked the travel arrangements and meetings for Dr Rye.

Morten Rye work shopped significant issues faced by the industries regarding the establishment and commercialization of selective breeding programs. Morten openly

related his experiences with similar situations overseas. A report was completed by Morten which outlines approaches and options that could be adopted to overcome the issues and problems discussed. Morten held debriefing sessions over the phone with some of these industries after his visit.

The Australian breeding programs for Pacific Oysters, Sydney Rock Oysters, and Barramundi were reviewed with respect to technical structure and proposed commercialization models for securing economically sustainable operations not relying on substantial external funding such as from R&D agencies. In addition, some cursory observations were presented for the prawn programs (for which no detailed background information for this review was provided).

Main observations and recommendations from Morten's review.
Pacific Oyster

- With recent modifications and improvements, the Australian Seafood Industry (ASI) now operates a technically well-designed and effective family based selective breeding program for Pacific Oyster, expected to produce significant genetic improvements for traits of key importance to the Pacific Oysters sector. The program structure is flexible and can also facilitate effective selection for improved resistance to diseases (e.g. POMS).
- The current business model in which the genetically improved seed is sold in competition with the two accredited multiplier's own mass selected lines offered at lower price is not viable.
- The present ASI role is not focused, and the company is clearly under-resourced with respect to being able to conduct all of its tasks. Current budgets are not reflecting true costs of operating the program, as parts are partly funded by ongoing R&D work.
- A new business model is proposed, in which
    - ASI limits its role to become provider of genetically improved material to accredited hatcheries serving as multipliers. This implies that ASI restricts its activities to coordination and management of all aspects of the technical breeding program operation.
    - The current ASI line of improved material is no longer branded and sold as a separate product in the market.
    - The multipliers are entitled to incorporate the genetically improved material into their marketed products.
    - ASI operations and costs are paid for by the multipliers, which compensate for increased costs by increasing the sales price of all spat produced.
- Main risk factors
    - The viability of the proposed business model depends on participation of both of the two major PO hatcheries.
    - Opportunistic hatcheries not participating may temporarily gain market shares.

Sydney Rock Oyster

- The selection program for SRO conducted by the Port Stephens Fisheries Institute (PSFI) has produced significant and impressive results in terms of improved growth and improved disease resistance for WM and QX.
- The breeding program currently implemented for Sydney Rock Oysters is not yet structured to take full advantage of the possibility for effective family based multi-trait selection. This issue is addressed in on-going R&D activities.
- Lack of consistent production capacity for high volumes of hatchery produced SRO spat is a major obstacle to efficient dissemination of genetic gains

obtained in the breeding nucleus to the SRO sector, and to reduce the industry's reliance on extensive use of wild spat which is a significant obstacle for obtaining reductions in production costs.

- In its recent stage it is not realistic that the breeding program for Sydney Rock Oysters can be fully commercialized and made economically self-sustainable in the short term.
- Priorities should be directed to:
    - Development of reliable hatchery techniques facilitating consistent high volume production of SRO spat.
    - Complete the restructuring of the breeding program to fully facilitate effective family based multi-trait selection, which requires extensive quantitative genetic competence. SOCo should be driving this process in order to ensure that the program is developed in line with the SRO long term priorities and needs.
    - It is recommended that SOCo establishes a management team with the core responsibility to coordinate breeding program activities in close collaboration with PSFI and with technical input from a competent provider of quantitative genetic services.

Barramundi

- The Australian Barramundi industry urgently needs to implement a cost-effective selective breeding program to lower production costs. This should be considered as a key element for sustainable farming of the species in the country.
- The Barratek initiative is solidly underpinned with extensive documentation of the sector's need for genetically improved seed and how a cost effective and bio secure program should be designed and implemented. The underlying documentation adequately discusses all relevant issues regarding the technical structure of a breeding program, the benefits and disadvantages of alternative models, and the risk factors involved.
- The proposed strategy of operating the program with one central breeding nucleus is strongly supported, and the GFB facility seems to be ideally equipped for this role.
- Reflecting the wide range of commercial production environments in which Barramundi is farmed the magnitude of GxE should be investigated in the early stage of the program. Experience from a number of other fish breeding programs do not suggest that GxE effects should be expected to lead to critical re-ranking of families across production environments.
- Current DNA fingerprinting for reconstruction of pedigrees in the proposed breeding program design may increase operational costs as compared to producing nucleus families by artificial stripping of single pairs of breeders. Single-pair mating is currently done routinely in breeding programs for other marine fish species including Atlantic cod, gilthead sea bream and European sea bass.
- The operational budgets and cash flow analysis presented in the Barratek Business Plan are realistic and well documented, and there appears to be no recommendable alternatives to the presented centralized program structure for implementation of a sector-wide, effective and sustainable long term program to the sector.
- With the current low combined production volume of Barramundi in Australia, it is not realistic to assume that the sector itself can absorb the full costs of establishing a sector-wide breeding program and therefore needs substantial contributions from public funds (RD grants or other). A breeding program may however have significant potential for significant revenues for international

sales of genetically improved materials to other Barramundi producing countries in the region and this option should be actively explored, especially if it can provide access to start up funds.

- The industry now appears to have reached a broad consensus on the way forward with a breeding program, based on the work done under the CRC, but have yet to commit to a funding structure for the program. In the present situation rather than relying on what appears to be an increasingly unlikely option of governmental support, it is strongly recommended that ABFA focuses its efforts on resourcing the startup of the breeding program activity as outlined in the current plans. In parallel it should develop alternative mechanisms to support the program over the longer term, which may include industry support, international sales and/or international investments.

Prawn

- The development of effectively domesticated populations of the Black Tiger prawn (*P. monodon*) which could be reliably reproduced in captivity would carry a tremendous commercial potential for those companies controlling these lines.
- In collaboration with CSIRO, three Australian prawn farming companies have made substantial progress towards effective domestication of the Black Tiger prawn. Through individual agreements with the research institution the companies are applying the same approach for their programs and hence following the same development trajectory, but they are at present in different stages (F10 vs. F2/F3).
- The programs have produced very significant changes in the target stocks, in particular with respect to increased growth rates and improved feed conversion efficiency. However, the reproductive capacity of the lines being domesticated is still significantly inferior to what can be obtained with wild broodstock and their reproductive reliability is low. This is substantially limiting the possibility to implement an effective breeding program for the species, and leads to increased infrastructure and operational costs in commercial production based on these lines.
- Considering the high costs associated with the development of a sustainable domesticated line of *Penaeus mondon*, it is surprising that the three programs appear to be run independently. It seems evident that industry collaboration involving exchange of material between the three programs would be beneficial to all programs.

Overall, the aquaculture industry in Australia is highly diverse and fragmented, and the potential for industry growth for all sectors is severely restricted due to tight and stringent environmental regulations. Considering the vast potential for increased aquaculture production in Australia and the rapid expansion of the aquaculture sectors in other parts of the world, it is surprising that the Australian authorities do not more actively facilitate and support increased aquaculture productions in the country.

Furthermore, it is evident that all Australian aquaculture sectors depend on use of genetically improved stocks to ensure sustainable production over the longer term, and therefore need access to core genetic services to implement and run cost-effective selection programs. In this perspective, co-funding an entity providing such services could be considered as a potential CRC legacy project. This entity could provide technical coordination, securing affordable access to genetic competence and technical infrastructure such as data base management systems. It would clearly provide significant benefits throughout all participating aquaculture sectors, and also stimulate broader communication and collaboration among the sectors in other areas

of joint strategic importance. It is here important to underline that the main elements of the genetic services needed are not core research activities *per se*, but in essence advanced technical commercial services.

Outcomes from Morten Rye's review
– ASI was restructured as a direct outcome of the review
- CSIRO were motivated to submit a legacy project proposal regarding the commercialization of genetic service provision entity for seafood selective breeding programs in Australia
- Mainstream Aquaculture were inspired to some extent by the review to development a CRC-P for rapid iteration selective breeding of barramundi which is now underway

Fourth event – Commercialisation of selective breeding industry master class

The third event organised by the project was an industry master class on the commercialization of selective breeding programs to coincide with the intended visit of Bjørn Skjævestad, owner of the Akvaforsk Genetics Centre, for the World Aquaculture Society conference in June next year. Bjørn is an investor in the businesses of breeding for aquaculture, marine ingredients for human health and nutrition and veterinary medical products, investment and business management. He is an owner and chairman of the Akvaforsk Genetics Centre (AFGC, leading provider of technical genetic improvement services to aquaculture industries worldwide), owner and chairman of VESO (leading supplier of fish and livestock veterinary medical products in Norway, which runs a clinical challenge testing facility for fish in Norway) and is CEO and owner of Altavida (a privately held investment and management company which invests in and manages ventures and opportunities targeting high growth international markets). The masterclass was to be held to coincide with Bjørn's visit to WAS, however Bjørn was ill and unable to attend. Bjørn did send a video presentation which was used to kick off a special session organised and chaired by Nick Robinson entitled "Breeding futures – How might the business of genetics and breeding unfold?" This session was well attended and generated a lot of discussion at the conference. An outline of the session content, and the abstract submitted by Bjørn is given below. The video of Bjørn's presentation is available from Nick Robinson on request.

Other speakers at the special session included

- Thomas Gitterle representing one of the world's largest shrimp breeding companies, SyAqua which is now part of the Gold Coin group of companies in Thailand,
- Jon Bailey from the New Zealand King Salmon company,
- Graham Mair of the Australian Seafood CRC and
- Matt Cunningham of Australian Seafood Industries.

Abstracts from the international visitors are included below.

SPECIAL SESSION - GENETIC FUTURES – HOW MIGHT THE BUSINESS OF GENETICS AND BREEDING UNFOLD?

Session Chair - Dr Nick Robinson

Nofima and Flinders University

There is great demand and potential for increasing world aquaculture production and efficiency. Selective breeding has been shown to be one of the most effective tools that we can utilise to improve the biological efficiency of production. However, less than 10% of world aquaculture production is based on genetically improved stocks. This is probably because of the large upfront costs of establishing selective breeding programs of a scale and complexity that will produce beneficial outcomes (strong genetic improvement in key economic traits), because of the relatively small size of our current aquaculture industries and willingness to pay for improved stock (smaller scale and less revenue compared to livestock) and because of the large numbers of different species under production, each requiring their own breeding program and specialised knowledge base.

There are however an increasing number of mature breeding programs in aquaculture that have moved out of the realms of R&D and are being commercialised. This session draws on international experiences regarding the commercial establishment, ownership and running of selective breeding programs. The speakers will consider a range of business and "cooperative" type models for running selective breeding programs. Where are we at now? What has worked well? What has not gone so well? What could be better done in the future? How does the selective breeding entity provide access to industry while protecting investment in the creation of genetically improved stock? Can a selective breeding business be a profitable venture in itself? Advantages/disadvantages of multi-species selective breeding businesses? What does an investor look for? What are the potential benefits for industry from a well-run profitable selective breeding entity?

THE BUSINESS OF AQUACULTURE GENETICS- LESSONS LEARNED AND REQUIREMENT FOR BUILDING A SUCCESSFUL AQUACULTURE GENETIC VENTURE

Bjørn Skjævestad

Akvaforsk Genetics Centre, Norway

To be successful in genetics from a financial point of view has been challenging (with some few and important exceptions). This might be surprising, knowing the important impact genetic improvement has had and still has on existing major meat (and aquaculture) production industries.

Most breeding programs are in the first generations, focused on improved growth and efficiency. The opportunity to improve the growth rate with a minimum of 10% per generation would result (at least theoretically) in a huge impact on the cost and competitiveness of the production.

Some challenges:

- The farmers are not capable of utilizing the improvements, mostly due to other biological challenges. (e.g. it doesn't help to have access to fast growing tilapia if the farmers are struggling with low oxygen in the water, or access to a 60% faster growing cod if the farmers are struggling with reproduction)
- The production volume in the industry is too small to fund a professional breeding program (a "chicken or the egg" problem)
- It takes time to establish a breeding program and get significantly improved materials to offer the market
- Competition from low cost, non-sustainable breeding programs

Some lessons learned:

- The genetic improvements need to be well documented in "real life"
- Efficiency as a trait is important for the long-term development of the industry, but improvements of traits that can have impact on disease resistance/health or perceived quality/price might be as important in the short-term.
- You need a long-term view – expect at least 5 to 10 years payback time
- Most successful stand-alone aquaculture breeding companies are controlling both the production and sales of seeds for production (e.g Salmonids: ova roe, Shrimp: Post Larvae, Tilapia: Fingerlings). Sales of broodstock, licensing or other types of arrangements are often just an add-on business.

- If you don't have access to several years of public grants or at least 5 years of full funding for the genetic improvement program, you need some kind of commitment from players downstream in the value chain

COMMERCIALIZATION EXPERIENCES FOR GENETICALLY IMPROVED STOCKS OF *Penaeus vannamei* IN ASIA AND AMERICA

Thomas Gitterle, SyAqua and Gold Coin

The use of genetic improvement programs in the shrimp industry is rather recent and hence the commercialization of the genetically improved stocks is still a challenge. Commercial breeding programs for shrimps started with *Penaeus vannamei*, and that has been one major reason why this species is the most cultivated shrimp species in the world.

As in any breeding program the definition of the breeding goal is paramount and there is a clear difference between the traits economically important in Asia and in Central and South America. In the western hemisphere, shrimp production is extensive with stocking densities ranging between 10 to 30 animals per square meter with pond sizes between 6 to 10 Ha. With such big areas it is very difficult to apply good biosecurity measures or disinfect the water in the ponds before stocking. Animals in such conditions cohabitate with endemic pathogens and therefore stock showing any degree of disease resistance is a major quality. In that area farmers are looking for SPR (specific pathogen resistant) rather than SPF (specific pathogen free) lines.

On the other hand in Asia the production system is based on high biosecurity measures, with the possibility to disinfect the water before stocking and consequently viral diseases tend to appear only after 60 days post stocking. Under such scenario disease resistance loses importance and the ultimate goal is fast growth. Hence in Asia farmers are looking for SPF animals with fast growth potential.

Since there is a negative genetic correlation between fast growth and resistance to at least two major viral diseases (WSSV and TSV) it has been very difficult to select animals that fulfill the need for the producer in both hemispheres. Breeding companies that put a high emphasis on growth might succeed in Asia but not in America and vice versa. Since growth has a higher heritability than any resistance to disease, the progress for that trait is easier to show in farms, and breeding companies that are stronger in that characteristic normally lead the market for both Postlarvae and commercial Broodstock in Asia. Making use of their competitive advantages, feed companies in Asia started their own breeding programs, or purchased well known breeding companies, to offer to their customers genetically improved seed for growth rate that perform well with the use of their feeds.

However with the appearance of a new disease in Asia (AHPNS or EMS) the fast growth perception has been changing rapidly since mortality appears normally during the first 30 days post-stocking and the biosecurity measures applied before don't seem to help much. This situation has opened new opportunities to other breeding companies that balance better growth, with disease resistance and pond survival in their breeding goal and probably also will open the market to breeding companies coming from the Americas with higher tolerance to diseases.

BREEDING A BRAND – THE NEW ZEALAND KING SALMON SELECTIVE BREEDING PROGRAMME

Jon Bailey, New Zealand King Salmon Company

The New Zealand King Salmon Company (NZKS) has been running a selective breeding programme (SBP) for Chinook (King) salmon *Oncorhynchus tshawytscha* since 1997. Originally designed to manage in-breeding while selecting for key

performance traits**, the SBP is now in its seventh generation and has developed into a complex management and marketing strategy** that is at the core of the NZKS business.

With a limited gene pool in NZ, and regulations limiting the import of new genetic stock, the establishment of a breeding programme was a prudent and logical step in the mid 1990s, when commercial salmon farming was expanding.

Early trait selection included performance and flesh quality. Some of these remain core to the programme, but with technological advances in environmental management, nutrition and husbandry, the focus has recently shifted to traits with a lower incidence and heritability. **Notable by its absence, however, is the need to select for disease resistance, as there are currently no commercially significant diseases affecting the King salmon industry in NZ.**

In addition to the genetic benefits of the SBP, the company has achieved a significant commercial advantage in the management of its IP. Since the start of the programme, NZKS has never traded any of its genetic stock. As a result it has created a unique breed of King salmon - Ōra King.

Ōra King is also a brand. As 'best of breed', it is a food service brand that supplies hand selected, premium grade salmon to discerning chefs around the world. The SBP lies at the heart of the Ōra King story.

The SBP has not been without its challenges and has had to adapt to changing market demands, new technology, and the limitations of being a very small player operating in a global salmon industry.

Despite these challenges, NZKS has a world-class breeding programme that supports its vision of inspiring people to experience superb King salmon dining.

Fifth event (participation available on request and enrolment) – Breeding basics- A short course for hatchery staff, managers and owners

The final event organised by the project is an open short course on breeding and genetics aimed toward hatchery staff, hatchery managers and owners of selective breeding programs. Interested parties are invited to contact Nofima and register for participation.

Target audience
The aquaculture innovation hub identified a need and desire for basic training in genetics at three levels: 1. For staff collecting data and organising the reproduction of animals in the hatchery, 2. For hatchery managers overseeing basic breeding activities, and 3. For business managers and owners interested in investing and profiting from genetic improvement programs

Plan
We originally planned a course involving mainly Australian geneticists (Nick Robinson, Graham Mair and Peter Kube), but we became aware that Nofima was preparing an online course targeted at the exact same audience and need (but with more international scope, more involvement of experts and more content), so it was decided that it would be better to make use of the availability of this course instead.

The Nofima planned course content and story board follows:

NOFIMA ONLINE COURSE

Target group

Farmers, hatchery managers, aquaculture breeding managers, students, [entrepreneurs, investors]

Pre-requisite

Participants of the course are required to have achieved a minimum of a high school level education.

Motivation:

The course is aimed at people who want to have basic introduction to aquaculture breeding, as well as those who want to refresh their memory and acquire more knowledge on aquaculture breeding opportunities, strategies and techniques.

Learning Outcome/objective

Participant in this course will acquire sound and basic knowledge and understanding of the use of traditional and modern fish selective breeding methods, as well as learn about the design of some major aquaculture breeding programs.

At the end of the course, participant should be able to consider different designs of breeding programs for aquaculture species, undertake performance and pedigree recording, and understand the concept and terminologies of selective breeding. Participant will also acquire introductory knowledge about use of genomic information in breeding programs for parentage assignment as well as making selection decisions.

Study design and plans

We aim to give an introduction to selective breeding in aquaculture through the use of video lectures, demonstrations and farmer/breeder interviews as well as exercises. In addition, examples of successful breeding programs using simple or advanced breeding strategies will be discussed. Assessment in this course is by way of exercises, mostly multiple-choice questions and hands on task requiring written

answers. Furthermore, there will be an online forum with the possibility of discussing assignments with fellow students and lecturers.

The course will be open for signing up twice a year (sem1=mid-April - end of May; sem2=last week of September - end of October). This will allow for discussions between student and with lecturers via an online platform. However, all year round, individuals may sign up for course but note that, this comes with limited support from lecturers.

One can follow the course in two ways:

1) By signing up for any of the semesters. The course would be given twice a year (sem1=mid-April - end of June; sem2=last week of September - end of October). By completing online mandatory quizzes, assignments and other tasks, a certificate of proof that the participant has completed the course will be issued.
2) Individual study plan. When a participant decides to undertake the course at any time of the year (i.e. different time-period from the sem1 and sem2), course materials will be available, however, support from the lecturers would be limited.

Participation cost: Cost of participating in the course are stratified based on internal co-operations with NOFIMA, country of participant (developed countries/developing countries) and whether a university student or industry officer status.

Participation cost: Cost of participating in the course are stratified based on internal co-operations with NOFIMA, country of participant (developed countries/developing countries)

Topics and content

1. Short introduction to the status, benefits and scope of aquaculture selective breeding ***(motivation for venturing into aquaculture production, organizational structure, selective breeding so far: possibilities and achievement in major industries-Norway, Asia, etc.)***

Lectures: Trygve Gjedrem, Ingrid Olesen

Short videos from Norwegian Salmon and cod breeding systems (AquaGen, SalmoBreed, local farms)

Lecture time: (20mins + 5mins videos)

Learning objective/outcomes:

a) Participant will acquire knowledge on the status, potential achievement and constraint in the aquaculture breeding industry

2. Aquaculture species as breeding animals (*Examples from Freshwater, brackish water and seawater [eg. cod, salmon, tilapia, carp, rainbow trout, prawns etc]. In cases where needed, effort would be made to tailor the species towards the audience)*

Lecturers: Bjarne Gjerde

Lecture time: (20mins + 5mins/species videos: farmer experience (e.g. salmon, Tilapia and cod)

Learning objective:

a) Participant will acquire knowledge on breeding important species in the aquaculture industry

b) Participant will learn about the success and challenges in several breeding programs for multiple aquaculture species

3. Defining breeding objective/goals for aquaculture species (how to *define breeding goals, stakeholder participation in defining breeding goals, measurement of traits to achieve breeding goals and weighing the different traits in the breeding goal)*

Lecturers: Ingrid Olesen, Bjarne Gjerde
Lecture time: (20mins)
Learning objective:

a) Participant will be able to help define breeding goals that are measurable, achievable and sustainable.
b) Participant would also learn about the relationships between breeding goals and expected outcomes in genetic progress in terms of selection response

4. Breeding strategies, mating designs and Selection Methods[1 & 2]

Lecturers: Bjarne Gjerde
Lecture time: 20mins x 2 + videos from a breeding company on collecting eggs and semen
Learning objective:

a) Participant will acquire knowledge on several selection methods used in aquaculture.
b) Participant would be able to learn about the consequences of applying the selection methods on genetic progress and genetic diversity (inbreeding)

5. **Design of simple and more advanced breeding programs [1 & 2]**

Lecturers: Bjarne Gjerde
Lecture time: 20mins x 2 + interviews from breeding organization on hatcheries, rearing tanks, etc
Learning objective:

a) Participant will be able to design simple breeding programs and discuss the main prerequisites as well as potential and challenges of applying more advanced programs.
b) Participant will acquire knowledge on the inter-play between genetic progress and inbreeding on several sets of aquaculture breeding programs.

6. Inbreeding and control of the rate of inbreeding

Lecturers: Solomon Boison
Lecture time: (20mins)
Learning objective:

a) Participant will learn about the causes and consequences of inbreeding in a breeding scheme.
b) Participant will be able to calculate inbreeding and rate of inbreeding using simple methods
c) Participant will acquire knowledge on methods/ways to control/manage inbreeding in a selected population

8. Recording of Phenotypes and Pedigrees, DNA sampling for Genotyping: recording traits of importance based on the identified breeding goals, methods of recording pedigrees (from simple to more advance methods (e.g. PIT tagging: effort should be made to demonstrate), collecting tissue (DNA) samples for tracing pedigrees (parentage assignment) and marker assisted selection and genomic selection.

Lecturers: Celeste Jacq, Mathew Baranski
Lecture time: (20mins) + demonstrations
Learning objective:

a) Participant will acquire more knowledge on the importance of recording phenotypes and Pedigrees in a breeding schemes
b) Participant will learn about PIT tagging in various aquaculture species
c) Participant will acquire knowledge on collecting DNA information in selective breeding. They should also be able to undertake DNA sampling and storage of the collected DNA.

9. Genotype by environment interactions in aquaculture

Lecturers: Panya Sae-Lim
Lecture time: (20mins) + Video demonstration of breeding farms vs. grower farmers
Learning objective:

a) Participant will learn the definition of GxE interaction, as well as its consequences to breeding programs
b) Participant will learn how to quantify GxE interaction and its implementation to breeding programs

10. **Prediction/estimation of breeding values and selection of breeding candidates [1 & 2]**

Lecturers: Bjarne Gjerde
Lecture time: (20mins) + videos from a breeding company
Learning objective:

a) Participant will be able to rank and select breeding candidates by simple methods
b) Participant will be able to estimate breeding values using phenotypic information about one trait of the breeding candidate and full- and halfsibs using simple selection index theory.
c) Participant will also know about the possibilities to estimate breeding values for multiple traits and by more advanced methods, and the advantages of these.

11. Dissemination and measuring of genetic gain and trends

Lecturers: Bjarne Gjerde
Lecture time: (20mins) + videos from a growers company
Learning objective:

a) Participant will be able to consider different methods for measuring selection responses, and their main advantages and shortcomings
b) Participant will understand different approaches for organizing dissemination of genetically improved material.

Participant will understand different approaches for organizing dissemination of genetically improved material.

13. Introduction to the application of genomic information in selection (marker assistant selection (MAS) and genomic (GS) selection)

Lecturers: Marie Lillehammer
Lecture time: (20mins)
Learning objective:

a) Participant will acquire knowledge on the difference between traditional pedigree-based selection and the use of genomic information in making selection decisions.
b) Participant will understand the difference between marker assisted and genomic selection and under which circumstances each strategy is useful.
c) Participant will acquire knowledge about cost-reducing strategies in genomic selection in aquaculture and requirements for data for different implementation strategies.

14. Consideration of different molecular genetic tools and chromosome manipulation

Lecturers: Mathew Baranski
Lecture time: (20mins)
Learning objective:

c) Participant will understand the difference between selective breeding using different molecular tools (traditional, MAS and genomic selection) versus the use of genomic modifications (transgenic) as a way of achieving genetic progress.

Course materials

1. Selection and Breeding Programs in Aquaculture : edited by: Trygve Gjedrem
2. Selective Breeding in Aquaculture: an Introduction (Reviews: Methods and Technologies in Fish Biology and Fisheries) – by Trygve Gjedrem and Mathew Baranski
3. *Additional material listing (books, papers, notes) from Lecturers*

«Story-board»
Module No:
Name of Module:

Aktivity no	Subject	Name of teacher	Student activity	Where and when (student)	Teaching methods & Tools	Need assistance from
1	Short introduction to the current status, benefits and scope of aquaculture selective breeding	Trygve Gjedrem, Ingrid Olesen	• Self-study • 2 research papers for reading	Virtual meeting point*	• Lecture time*: (20mins) • 2-5mins each of videos from Norwegian breeding companies (AquaGen, SalmoBreed, local farms)	Student for video recording interviews?
2	Aquaculture species as breeding animals [*eg. cod, salmon, tilapia, carp, rainbow trout, prawns etc*]	Bjarne Gjerde	• 4-page reading material from Gjedrem and Baranski (2009)	Virtual meeting point	• Lecture time*: (20mins) • 2-5mins/species videos: farmer experience (e.g. salmon, Tilapia and shrimp/prawn?)	Student for video recording interviews?
3	Defining breeding objective/goals for aquaculture species	Ingrid Olesen, Bjarne Gjerde	Read chapter 16.4 in Gjedrem (ed) book (2005) Assignment to be submitted after 1 week + MCQ?	Virtual meeting point, online discussions-board*	• Lecture time*: (20mins)	
4	Breeding strategies, mating designs and Selection Methods[**1 & 2**]	Bjarne Gjerde	• Read chapter 10 in Gjedrem (ed) book (2005) or ch 6 in G&B (2009). • MCQ with instant answers	Virtual meeting point	• Lecture time* (20mins each [1] & [2]) • videos from a breeding company on collecting eggs and semen and interview with salmon breeder to explain how they consider options of crossing and pure breed	Online videos + Student for video recording interviews?

					selection	
5	Design of simple and more advanced breeding programs [**1 & 2**] – [*Structure of breeding programs*]	Bjarne Gjerde	• Chapter 11.1-11.7 in Gjedrem (2005) or ch 7 in G&B (2009)? • MCQ with instant answers	Virtual meeting point	• Lecture time* (20mins each [1] & [2]) • Interviews from breeding organization on hatcheries, rearing communities, etc	Online videos + Student for video recording interviews?
6	Inbreeding and control of the rate of inbreeding	Solomon Boison	• Chapter 6 in Gjedrem (2005) or 4.6 in Gjedrem & Baranski (2009)? • MCQ with instant answers • + Assignment to estimate F and deltaF?	Virtual meeting point, online discussions-board	• Lecture time* (20mins)	
7	Recording of Phenotypes and Pedigrees, DNA sampling for Genotyping	Celeste Jacq, Mathew Baranski	Reading chapter 16.9, 16.13		• Lecture time* (20mins) • Video demonstration of tagging, weighing and photo box measures of filet fat and colour? • Video demonstration of DNA sampling	Internally generated videos + Student for video recording interviews?
8	Genotype by environment interactions in aquaculture	Panya Sae-Lim	• Sae-Lim et al. (2015) • Additional reading materials Ch. 10 in G&B (2009)	Virtual meeting point	• Lecture time* (20mins) • Video demonstration of breeding farms vs. grower farms	

9	Prediction/estimation of breeding values and selection of breeding candidates [**1 & 2**]	Bjarne Gjerde	• MCQ with instant answers • Additional reading materials (ch 9 in G&B(2009)) and assignment (EBV)	Virtual meeting point Online discussion boards	• Lecture time* (20mins each [1] & [2])	
10	Dissemination and measuring of genetic gain and trends	Bjarne Gjerde	MCQ	Virtual meeting point	• Lecture time* (20mins) • Videos from a growers company – interview about dissemination strategies (salmon and tilapia?)	
11	Introduction to the application of genomic information in selection (marker assisted selection and genomic selection)	Marie Lillehammer	• MCQ with instant answers • Additional reading materials	Virtual meeting point	• Lecture time* (20mins)	
12	Consideration of different molecular genetic tools and chromosome manipulation.	Mathew Baranski	Additional reading materials	Virtual meeting point	• Lecture time* (20mins)	

Lecture time* = PPT + video tapped delivery with voice over in a semi-classroom, **NOTE: ALL lectures will be pre-recorded**
MCQ = online "Multiple choice questions" embedded with instant answers to the questions
Virtual meeting point = Lecture will be released on the lecture day, participant can assess it any time after it been released
Online discussions-board* = Online discussions-board with participant posting questions and been answered by lectures and other participants

3.3 Visits to/from Norway facilitated or planned by the project.

- Graham Mair of the Australian Seafood CRC is introduced to relevant staff in Nofima and AFGC at Sunndalsøra and Ås by Nick Robinson. Planning is carried out for visits and exchanges.
- Peter Kube CSIRO visits Norway in July 2010 and holds discussions with Hossein Yazdi and Morten Rye of the Akvaforsk Genetics Centre and Nofima staff about development of databases and associated systems for selective breeding. Nick Robinson assisted with planning and introductions.
- Nick Elliot CSIRO travels to Norway as invited opponent for Tale Drenstig's PhD, for a meeting with Morten Rye and for the Fish Breeders Round Table discussions in Stavanger.
- Richard Taylor CSIRO travels to Norway with a bursary from the Nofima exchange program project. Visit and discussions in Norway with Harald Takle Nofima and others results in project funded by Seafood CRC on salmon resilience. Solutions that could be directly applied to tackle "summer gut syndrome" were discussed with the Aquaculture Protein Centre in Oslo and Sunndalsøra. Visited research cages and recirculation aquaculture systems (RAS) that are run on a semi-commercial footing. Strengthened research linkages in understanding salmonid gut health related to environment and nutrition. Following discussions with Dr Ingrid Olesen of Nofima Marin, CSIRO are named as collaborators on a proposed project ('HeartBeat') which was submitted to the Norwegian Research Council on 12/10/2011.
- Brad Evans (SalTas) travels to Norway with a bursary from the Nofima exchange program project. The visit allowed Brad to gain an understanding of how salmon breeding programs in Norway have become commercially driven and vertically integrated. Nick Robinson facilitates by providing contact details and suggestions.
- Alex Safari, post-doctoral researcher at Flinders University funded by the Australian Seafood CRC (by then working for the World Fish Centre in Malaysia), travels to the Fish Breeders Round Table meeting and to visit Nofima.
- Malcolm Brown of CSIRO visits Norway (Petter Wold at Nofima Ås, organised by Nick Robinson) to evaluate methods for predicting oyster biochemical composition.
- Yvonne Sheehan, Manager of SalTas, travels to Norway in 2011 and visits AquaGen, Nofima and other companies involved with selective breeding of Salmon in Norway. Nick Robinson provides Yvonne with contacts and suggestions.
- Adam Main (Chief Executive Officer at the Tasmanian Salmonid Growers Association visited Norway in 2011 to attend AquaNor and to talk with researchers and industry interested in recirculation systems for salmon, nutrition research etc. Nick Robinson provided Adam with contacts and suggestions.
- A mini workshop on the international commercialisation of selective breeding programs and genetic services was held at Nofima Måltidets Hus Stavanger Norway in August 2011 (agenda and attendees described below). A number of Australian and Norwegian participants attended. The workshop was organised and hosted by Nick Robinson at Nofima Stavanger.

- Paul Whatmore, a PhD student from the University of Sunshine Coast, visited Matthew Baranski and Hooman Moghadam from 18 Nov to 8th Dec 2012, to analyse data for his PhD project on gene expression and function involved with fat deposition in yellowtail kingfish, using RNA-seq data. Matthew Baranski is a recognised expert in bioinformatic analysis of genomic and transcriptomic information from aquaculture species (see list of relevant publications at http://www.nofima.no/en/person/matthew.baranski).
- Len Stephens (Australian Seafood CRC) visits Stavanger. Nick Robinson provides local contact details for Nofima Måltidets Hus in Stavanger.
- Dr Øyvind Fylling Jensen CEO of Nofima visited and discussed institute management with Senior Managers of the Australian Seafood CRC, CSIRO, SARDI, Flinders University and FRDC in March 2010 at Nofima's own cost. Nick Robinson planned and guided Dr Fylling Jensen on the visit.
- Other plans to visit Norway that were facilitated by Nick Robinson, but not eventually carried out by the participants include
    - Miles Wyse, Hatchery Manager of Clean Seas Tuna
    - Jenna Boyer, Researcher at Flinders University
    - Medhi Doroudi, Manager of Animal Health at PIRSA
    - John Henshaw of CSIRO to visit Nofima and to try a new method for the analysis of pooled SNP data taking account of pedigree information.
    - Mike Taylor of NZ keen to find funding to involve Bjarne Gjerde in helping with mating design and breeding program structure
    - Jane Symonds of NIWA keen to receive Norwegian students and looking for other means to collaborate (eg. sharing simulation program knowledge).
    - Nofima keen to send a student to work with ASI on oyster selective breeding and hatchery management
    - Anton Krsinich of Great Southern Waters keen to visit Norway for the fish breeders round table meeting

3.4 Other reports derived from the project.

Utility of Genotyping by Sequencing (GBS) for abalone fishery studies
Nick Robinson, Senior Scientist, Nofima/Flinders University

What is Genotyping by Sequencing?

The development and function of all living things is coded by the sequence of billions of base nucleotides in the deoxyribonucleic acid (*DNA*) molecule. The four bases which form the code are adenine (*A*), cytosine (*C*), guanine (*G*) and thymine (*T*). Parts of the DNA sequence (all of which is referred to as the genome) codes for genes which are transcribed and translated into proteins in a process known as gene expression.

Technologies for DNA sequencing have been rapidly advancing and have become more affordable over the last 10 years. These advances have made it feasible to compare the "whole genome" of individuals sampled from a population. Different types of sequencing

techniques can be used to study variation in the DNA code (known as single nucleotide polymorphisms or *SNP*s), the expression of genes (ie. how is the expression of particular genes is modified in response to particular stimuli under different circumstances/ cells /tissues / stages of development) and to study the level of methylation at base positions throughout the DNA molecule (which is known to play a role in regulating gene expression and can be inherited in some circumstances).

Genotyping by sequencing (GBS) makes use of these new sequencing technologies to record the bases (*A*, *C*, *G* or *T*) found at numerous positions throughout the genome in particular individuals. As the chromosomes of most sexually reproducing organisms exist in pairs, one of each pair inherited from their father and the other from their mother, two different bases, or two copies of the same base, will be detected. The combinations of these two bases at each position across the genome is called the genotype.

GBS data and analysis

The new sequencing technologies create data files that are many terabytes in size. The raw data that is created requires sophisticated algorithms and super computers for analysis. First the small fragments of sequence must be quality controlled, assembled into larger contiguous stretches and aligned to detect the positions where SNPs occur. Next, the SNPs across the genome in each individual need to be scored as genotypes. Based on the sequence of bases surrounding the SNP, it is possible to determine if the SNP occurs in or near a gene sequence, and to identify the gene and its putative function in most of these instances.

Depending on what information is available about the individuals that have been sampled for GBS a number of different analyses can be performed. Geographic or Oceanic Information Systems are large databases that map environmental parameters such as water temperature, strength and direction of currents, depth, substrate, oxygen, nutrient and pH etc. to fine scale grids (eg. the NOAA World Ocean Database, www.nodc.noaa.gov, which has 0.1 degrees' resolution for data recorded over the last 100 years). Samples for GBS taken from individuals fished from known GPS coordinates across the range of a species can be used to look for SNPs with genotypes showing strong associations with the geo-spatial data recorded in these Oceanic Information Systems.

How could GBS be used to gain knowledge for managing abalone fisheries?

Abalone fisheries are currently managed using broad scale information about genetic connectivity, population size, recruitment potential, catch rates etc. To maintain the genetic health of the fishery efforts have been made to limit/avoid overall loss of genetic diversity and to maintain natural patterns of genetic variation caused by population structuring. But what if we had more specific information about the types of genetic variants that were important for adapting specific individuals to specific habitats or conditions? GBS is already being applied to detect such genetic variants in a number of marine species. Information about the specific genetic variants found in particular individuals can be used to guide fisheries management or re-stocking decisions to maintain a high frequency of genetic variants influencing specific adaptations of importance in the local environment. Information about the allele frequencies of genes involved in affecting adaptations to particular environmental conditions could be used to more accurately model how the genetics of the fishery will change under different management (eg. restocking) or environment (eg. climate) change scenarios. Changes could be detected by repeatedly sampling and monitoring allele frequencies over the generations. So not only could GBS be used to guide or improve management decisions, it could also allow fishery managers to monitor and evaluate the genetic health of the population.

Habitats across the range of each abalone species differ substantially. For instance, water temperatures and dissolved oxygen differ markedly depending on geography (site exposure to the open ocean, water currents and wave action). These factors create strong differential selection pressures on genes that affect an individual's ability to survive in the different populations. However, due to the high fecundity and ability for dispersal and genetic mixing among abalone, signatures of such selection can be difficult to detect. Abalone fisheries consist of large population numbers and all species have a wide dispersal potential (as larvae). This leads to a mixing of genetics over the species range which creates homogeneity in the genotypes detected at most positions in the genome. To be able to detect genes under strong selective pressures in populations with such characteristics there is a need to study the genetic variation at many thousands of positions spread throughout the animal's genome and to look for associations with detailed geo-spatial data. The application of GBS for detecting such associations has been demonstrated in recent unpublished work by Flinders University on *Haliotis roei* and *H. laevigata* abalone in Western and Southern Australia (publications in preparation, Flinders University).

What does the future hold?

New technologies such as GBS are allowing us to gain a better understanding of the evolutionary forces and genetic changes influencing the health and sustainability of our fisheries. These technologies are advancing at a rapid pace and becoming cheaper and more powerful largely because of the research efforts being made in human genetics. Such advances can be quickly adapted and applied to help improve our knowledge of the complex population dynamics and influence of geospatial environmental differences on the genome of fish and shellfish. This detailed information will provide important clues for better managing fisheries and for monitoring and evaluating the effects of environmental disturbances and fishery management practices. In short, GBS is a valuable tool that will become more and more relevant to fishery studies.

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3.5 Evaluation of success.

The activities linked to the project have resulted in new collaborative initiatives, the generation of fresh ideas, new experiences and improved knowledge about the systems, methodology and research used in Norway. Outcomes derived from visits and workshops funded through Nofima Exchange travel bursaries have been reported to the Seafood CRC. In all, the project has been an overwhelming success with large participation and interest from both industry and researchers, generating spin-off research project collaborations and fresh ideas. The project leader is not able to provide a comprehensive evaluation of the success of this project as many of the learnings that participants have drawn from the project activities have been private or may be held confidentially by the participants. However, feedback from the project participants, and developments that could be attributed partially or fully to the project have been captured as success indicators:

First workshop

We evaluated the success of the first workshop in two ways. After each session we looked at topics that arose which participants thought might change the way that they do their research, new ideas they might have gained for new projects, ideas for collaboration, people they might contact or seek advice from. We also did an evaluation of whether we should hold the workshop again and how the workshop might be run differently next time if we were to run it again.

The following points arose after the evaluation of the sessions:

- Richard Taylor and Jane Symonds were keen to contact Jorgen Ødegård (Nofima) with regard to discussions about new methods for the analysis of survival data and to contact Harold Takle (Nofima) and the breeding companies (eg. Aquagen) regarding TrainFish and heart deformities, function and fat.
- Kari Kolstad and Graham Mair remarked about how this has opened up new networking opportunities and that it would be good to continue the workshop as a regular process.
- Peter Kube remarked about how the workshop was a great opportunity to obtain some peer review and check of the quality of our work.
- Jane Symonds is now thinking about new applications for studying external parasite resistance in Marine species.
- Richard Taylor is keen to look into the robustness of fish under different feed environments.
- There was also a comment that some in the workshop will now consider looking at the prediction error variance in relation to the response they see in their simulations.
- Many were interested to explore further with Kari Kolstad, Turid Mørkøre and Peter Wold techniques for the measurement of fat and colour on live fish.
- Brad Evans was interested in exploring opportunities for cryopreservation further and was interested in the concept of having “connectedness” in the data and how that can help with analysis.
- Jane Symonds, Fiona Heley and others were keen to see more collaboration between those doing simulation modelling (inbreeding, bioeconomic modelling etc). Nick Elliot suggested that this might be something that the CRC and AAGA could contribute towards for abalone. There are also opportunities to collaborate on kingfish.
- John Henshaw suggested that we should compare runs of our simulations under the same conditions as a quality control step.
- Nick Robinson would like to explore ways of valuing inbreeding depression in these bioeconomic models so that the costs of small family sizes are made

clear. One suggestion was that we should go back and look at the earlier population and conservation genetics work on predicting safe levels of inbreeding and loss of genetic variation.

- Exploiting "unique" features of fish. Raul Ponzoni mentioned that because fish have unique systems and problems, we need to make different considerations than we do for livestock breeding. Maybe in some instances we should consider treating fish more like plants and creating inbreeding lines. The concept of natural exposure and vulnerability to inbreeding was discussed, as maybe some species are more tolerant than others to inbreeding, so for some you might be able to get away with much higher levels of inbreeding. Some carp breeding programs have however been cited as failures because of inbreeding problems.
- Bjarne Gjerde questioned why we use so many different mating designs (numbers of males over numbers of females etc).
- In developing economic weights there was a suggestion that maybe we should be going back and considering what was done in livestock 20 years ago in Australia. That maybe we need to just consider very simple effects on the cost of production before valuing meat quality. But it was also recognized that the industry in Australia largely consists of farmers, and that the weights we make are influenced mostly by the short-term difficulties that these farmers face and not longer term or market driven meat quality trait problems.

Review of selective breeding program commercialisation

The review prepared by Morten Rye of the Akvaforsk Genetics Centre has been picked up with great interest in Australia. He also held some debriefing sessions with the Oyster industry and with the Seafood CRC. CSIRO and the oyster and Barramundi industries found the discussions with Morten Rye very enlightening and useful. Some of the successful tangible outcomes that could be partially or wholly attributed to Morten's visit include:

- CSIRO (in collaboration with Graham Mair and Nick Robinson at Flinders University) were motivated to submit a legacy project proposal regarding the commercialization of genetic service provision entity for seafood selective breeding programs in Australia. Business consultants were employed by CSIRO and scoped the entity. A report on this project was submitted to the Australian Seafood CRC. Part of the scope was to evaluate the possibility of partnering with a Norwegian genetic services provider AFGC on international areas of work.
- Another outcome that may have been stimulated by Morten's visit was that ASI, which was operating under royalties collected from the industry, is now moving to a whole of industry breeding levy to fund breeding service and research activities.
- Mainstream Aquaculture were also inspired to some extent by the review (and by other ground work on selective breeding for barramundi undertaken by the Seafood CRC) to development a CRC-P for rapid iteration selective breeding of barramundi which is now underway. Through the CRC-P the intent of the project is to build a world leading selective breeding program for barramundi that will supply genetically improved seedstock nationally and internationally.

Visits by researchers to Norway

The outcomes and outputs from the visits by Brad Evans of SalTas and Richard Taylor of CSIRO (who were participants in the first workshop) have been detailed in separate reports submitted to the Seafood CRC, but include in the words of Drs Taylor and Evans:

- "Understanding of how salmon breeding programs in Norway have moved on from the early supported R+D phase to become commercially driven and vertically integrated"
- "Strengthened links with researchers and commercial breeding programs attempting to develop more 'robust' fish and improved cardiovascular function"
- "Visited research cages and recirculation aquaculture systems (RAS) that are run on a semi-commercial footing."
- "Strengthened research linkages in understanding salmonid gut health related to environment and nutrition."
- "Following discussions with Dr Ingrid Olesen of Nofima Marin, CSIRO are named as collaborators on a proposed project ('HeartBeat') which was submitted to the Norwegian Research Council on 12/10/2011."
- Four talks presented by Richard Taylor and Brad Evans to meetings in Norway
- "Enhancement of knowledge and understanding of the various approaches taken to genetically improve Atlantic salmon stocks in the major salmon producing countries of Norway, Scotland and Chile."
- "A greater understanding of the commercial structure of breeding companies, hatcheries and on-growers in other parts of the world."
- "Presentation to an international audience of the current status of the Tasmanian Atlantic Salmon Selective Breeding Program."
- "Feedback from World leaders on the current strategies for genetic improvement in Tasmanian Atlantic Salmon was positive, with our program being able to provide insights for others that are moving towards a system of freshwater maintained broodstock."
- "Linkages made with international experts in fish and animal breeding. Opportunities for ongoing collaboration within this network will prove invaluable as the Tasmanian SBP moves on from the current research agreement with CSIRO."

Other outputs highlighting success of the project

- Nick Elliot CSIRO joined as a co-investigator on a Norwegian Research Council funding application "Genomic delousing: Utilising the Atlantic salmon genome sequence to increase resistance to salmon lice" (PI, Nick Robinson, Nofima, not funded).
- CSIRO and SalTAs join with Nofima as collaborators on another funding application toward the Norwegian Research Council called "ClimaSal" (Climate Adaptability in Atlantic Salmon).
- Abigail Elizur University of Sunshine Coast joined as a co-investigator on a Norwegian Research Council funding application (PI, Nick Robinson, Nofima, not funded)
- Nick Elliot travels to Norway as invited opponent for Tale Drenstig's PhD, for a meeting with Morten Rye and for the Fish Breeders Round Table discussions in Stavanger.
- Yumbah abalone continues to implement an abalone breeding program to supply seed for its Port Lincoln sites utilising the latest genotyping by sequencing technologies and genomic selection under the guidance of Nofima experts.
- Malcolm Brown of CSIRO devised methods for predicting oyster biochemical composition using NIRS http://www.oysterstasmania.org/downloads/ios4-

presentations/Brown-IOS4-presentation.pdf after visiting experts in the use of NIRS technology (eg. Jens Petter Wold of Nofima) in Norway (meeting facilitated by the project).

Summary of main success measures against performance indicators

Performance indicator	Success measures
1. *Application for new collaborative projects with partners in leading aquaculture research institutes overseas*	• Australian research groups were included as partners in a number of Norwegian research applications through the contacts made in the project (eg. CSIRO and USC). • Technical knowledge from the Norwegian contacts has been adapted and implemented to benefit selective breeding programs in Australia (eg. near infra-red spectroscopy, genotyping by sequencing and genomic selection)
2. *Breeding companies in Australia share information, form alliances and or establish collaborative agreements with breeding companies overseas*	• Owners of breeding companies overseas have shared knowledge and experience which has benefitted the running of selective breeding businesses in Australia (e.g. Australian Seafood Industries)
3. *Breeding is embraced as a business opportunity in its own right in Australia*	• New selective breeding programs have developed in Australia and are considered as an important component of the business platform for some companies (e.g. Mainstream Aquaculture for barramundi). The embrace of breeding as a business activity in its own right was stimulated to some degree by the activities of this project.

4. Benefits and Adoption

Benefits and adoption are described as part of the evaluation of the success of the project in the above section. These include changed selective breeding business practice (Australian Seafood Industries oyster business model), initiation of new breeding programs for farmed species in Australia (barramundi and abalone) and implementation of technologies and knowledge derived from Norway (e.g. Near infra-red spectrometry for the oyster industry and ultra-high throughput genotyping technologies and genomic selection for the barramundi and abalone industries).

5. Achievement of Planned Outcomes

5.1 Public Benefit Outcomes

The project resulted in less replication of research and more collaboration internationally. Knowledge transferred in the project is enabling breeding programs for major seafood species to be established and run in a sustainable and efficient manner (using the latest technologies and under stable business models) so that consumers can be ensured a consistent supply of high-quality Australian seafood

5.2 Private Benefit Outcomes

Planned outcome 1:

One or more sustainable breeding companies operate in Australia by the end of CRC

Change benefiting industry from planned outcome 1:

Companies that were influenced in some ways to change breeding and business strategies to act more sustainably include:

i. ASI – oysters. New business structure.
ii. Mainstream Aquaculture – Barramundi. Focus on breeding and new CRC-P.
iii. SalTas – salmon. Modification of technical breeding practices.

Planned outcome 2:

International collaboration is established in genetic improvement and commercialisation by the end of the CRC

Change benefiting industry from planned outcome 2:

CSIRO and UQ researchers collaborate with international partners on grant applications in Norway

Planned outcome 3:

International best practice is being implemented by the majority of Australian aquaculture breeding companies

Change benefiting industry from planned outcome 3:

Aquaculture breeding companies were audited and took on board recommendations from leading international experts like Morten Rye AFGC.

Other private benefit outcomes:

Across the aquaculture industries the sectors that participated and benefited directly from the education, training and exchange program with Nofima were existing producers, government departments, institutes, universities, entrepreneurs and established selective breeding programs or hatcheries (businesses or cooperatives). These industries and sectors fell into the four interest groups described in the needs section above.

Existing and potential selective breeding program owners, business managers and hatchery managers were educated about,

I. how commercial selective breeding programs overseas have successfully developed,
II. what their strategies have been for marketing, pricing and profitability, research, internationalisation, minimising risk etc.
III. How has ownership changed and affected these strategies?

Breeding scientists were educated about, and experience first-hand,

I. the basics of establishing and running a selective breeding program
II. the latest developments in quantitative genetic theory as applied to aquaculture breeding programs
III. the latest research underway in Europe and Scandinavia on aquaculture genetics and breeding

The project has resulted in a more vibrant, knowledgeable, world-wise, entrepreneurial and progressive aquaculture genetics community in Australia.

The broader benefits of the application of world's best practice in genetic improvement will be the sustainable supply of high quality seed into Australian aquaculture industries resulting in highly significant increases in production efficiency and profitability. Evidence to date has shown that well implemented genetic improvement program can be responsible for at least 1/3 of productivity improvements gained from aquaculture development.

6. Conclusion

The education and training program with Nofima opened-up communication between Australian and international scientists and companies involved in fish selective breeding, and in some instances transformed the establishment and running of selective breeding programs for Australian Aquaculture. Numerous visits occurred between Norway and Australia, creating new links with expert knowledge providers and experienced aquaculture breeding industries overseas. The exchange of knowledge generated by the project lead to changed technical and business practices for existing selective breeding programs (e.g. oyster), the initiation of new breeding programs in Australia (e.g. barramundi) and the implementation of new and latest technologies for breeding (e.g. near infra-red spectrometry for oysters, genotyping by sequencing and genomic selection for abalone and genomic selection for barramundi).