Review of Australian breeding programs for Pacific Oysters, Sydney Rock Oyster, Barramundi and prawns

Dr Morten Rye

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This project was instigated by Flinders University, Sturt Road, Bedford Park, SA 5042, Australia and carried out by the Akvaforsk Genetics Center A/S, Sjølseng, N-6600 Sunndalsøra, Norway

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Australian Government
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An Australian Government Initiative

Non-Technical Summary

2008/769 Review of Australian breeding programs for Pacific Oysters, Sydney Rock Oyster, Barramundi and prawns.

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PROJECT OBJECTIVES:

1. To make recommendations aimed to facilitate the long term sustainability of the selective breeding programs in Australia
2. To ensure that the process and progress of the review is communicated clearly and transparently to industry stakeholders
3. To review options for the production of a generic selective breeding genetic database (go no-go decision subject to action plan)

Implementation: Dr Morten Rye of the Akvaforsk Genetics Centre, Norway, was selected as the investigator and Author for the review. Dr Rye travelled to Australia for two weeks to conduct the interviews for the review. Dr Rye's visit was also supported by a linked project (2008/772). Objective three was removed at the request of the Australian Seafood CRC.

OUTCOMES ACHIEVED

Options/recommendations for the commercialisation of these specific breeding programs leading to decisions on future directions and business plans for commercialisation of those programs have been presented to each of the sectors concerned. The review either directly or indirectly led to:

1. New plans for the commercialisation of oyster selective breeding
2. A new project to assess possibilities for the commercialisation of genetics services in Australia (led by CSIRO)
3. Acceptance of a centralised selective breeding model by the barramundi industry and acceptance that alternative funding options for selective breeding need to be explored

LIST OF OUTPUTS PRODUCED

Report by Dr Morten Rye of the Akvaforsk Genetics Centre Norway with recommendations (incorporated as the main body of this final report to the Australian Seafood CRC). Dr Rye reviewed the Australian breeding programs for Pacific Oysters, Sydney Rock Oysters, and Barramundi 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.

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Graham Mair, Len Stephens, Chris Calogeras, Justin Forrester, Wayne OConner, Scott Parkinson, Matt Cuningham, Rachel King, Hayden Dyke, ABFA, APFA, Shellfish Culture, Cameron of Tasmania and CSIRO.

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Prepared for
Seafood CRC, Australia

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NORWAY

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Preface

This review of on-going and planned Australian breeding programs for Pacific Oysters, Sydney Rock Oysters, Barramundi and prawns (*P. monodon*) has been contracted by Seafood CRC.

The primary objective for the work has been to assess the technical structure of the selective breeding programs and assess the scope for commercialization in order to make them less reliant on continued public funding.

Due to lack of detailed background information about the prawn programs, the comments made regarding these are limited to cursory observations based on brief conversations with industry representatives and Nigel Preston (CSIRO).

The work is primarily based on extensive background information provided by the Seafood SRC for oysters and Barramundi (Annex 1), and information shared during meetings with key personnel involved in management or technical operations for the respective programs during my visit to Australia September 3 – 15 (Annex 2).

Sunndalsøra, October 15, 2012

Morten Rye

1. EXECUTIVE SUMMARY

The Australian breeding programs for Pacific Oysters, Sydney Rock Oysters, and Barramundi have been 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 are presented for the prawn programs, for which no detailed background information for this review was provided.

The main observations and recommendations are the following:

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 (e.g. CSIRO).

Barramundi

- The Australian Barramundi industry urgently needs to implement a cost-effective selection 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.
- The for recurrent 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 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 productions 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.

2. BACKGROUND

Selective breeding programs are major drivers for the development of sustainable and profitable aquaculture productions. The use of genetically improved stocks resulting from well-designed breeding programs has led to dramatic improvements in performance and very significant and sustained reductions in production costs. For a key trait such as growth rate, genetic gains in the range of 10-15% per generations are documented for several aquaculture species, implying that growth rates can be doubled in 5-7 generations. These numbers refer to sustained responses in the breeding nuclei, the genetic level in effective dissemination lines may be substantially higher. While basically the entire world production of Atlantic salmon now is based on highly selected stocks, the uptake of this powerful technology for other species has been slower. For a recent review, see e.g. Gjedrem et al., 2012[1]. Investments in effective breeding programs give very high long term returns, since selection responses in the target populations are cumulative and permanent.

Selection programs

Simple and low cost individual (mass) selection programs can be highly effective for improving traits recorded on live breeding candidates (e.g. growth rate) and binary traits (e.g. general survival and resistance to specific pathogens) of low frequency facilitating large selection differentials. The longer term viability of mass selection programs, however, depends heavily on appropriate measures for controlling the accumulations of inbreeding in the breeding populations. This can be achieved by rearing full-sib groups from individual pairs of parents separately through initial periods with mortalities, before pooling a limited number of animals from each family and rearing them communally until maturation and selection. Low cost mass selection programs are typically implemented for species with low production levels prohibiting justification of the costs associated with more advanced breeding programs. Mass selection programs are usually run for a limited period of time only, before they are often transformed to sib-selection programs as the target industries mature and production increases.

The industry standard for genetic improvement programs are more advanced sib-selection (often termed 'family based') programs. Sib selection programs facilitate effective selection for all types of traits including those that can be recorded only through destructive tests (e.g. carcass quality) or disturbing tests (e.g. disease challenge). These programs also provide increased selection accuracy for traits of medium (e.g. growth) and low (e.g. survival) heritability, but are costly to implement and operate as they require pedigreed populations obtained by use of physical tags or extensive genotyping. Inbreeding levels in family based programs can easily be monitored and controlled since genetic relationships among candidates are known.

Funding and commercialization

Implementation and running of advanced breeding programs involves complex and costly operations (brains and money), and is associated with substantial biological and financial risks. Due to the high reproductive capacity of most fish, crustaceans and bivalves, unauthorized reproduction and use of improved stocks tends to be

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[1] Gjedrem, T., Robinson, N. and Rye, M., 2012. The importance of selective breeding in aquaculture to meet future demands for animal protein: A review. Aquaculture 350–353, 117–129

widespread for many species. Biological as well as legal protection mechanisms against such unauthorized reproduction are weak. Sustaining a high and stable genetic progress in the breeding nucleus combined with dissemination of highly selected seed of narrow genetic background is mostly used to achieve some level of biological protection, as every new generation of seed is significantly better performing as compared to earlier generations and the material sold for on-growing ill-suited for reproduction. Nevertheless, this strategy offers only limited protection. Stronger biological protection could be achieved by dissemination of sterile animals such as triploids, but appears not to be widely implemented. Likewise intellectual property rights and alternative legal protection measures for genetically improved material in livestock and aquaculture tend to be weakly developed. Adding to the complexity is the fact that for many aquaculture species fry and fingerlings of wild stocks are easily obtained at low cost, and farmers are often not willing to pay a premium price for genetically improved material.

Hence for emerging low volume aquaculture industries, public funding sources are instrumental for getting genetic improvement programs up and running. However, operations must plan for transition to economically self-sustainable operations, as public funding tends to be available only for a limited period of time. For emerging farmed species the cost of implementing advanced improvement programs may not be justified due to low production volumes and low level of sector integration, and extended private/public partnerships may be required for fair risk sharing.

3. PACIFIC OYSTERS

Industry needs

Over the last decade a major genetic improvement program has been established for Pacific Oysters in Australia, in recognition of its fundamental role for the development of sustainable and cost effective production. The program is owned and operated by Australian Seafood Industries (ASI), a joint venture company established and owned by oysters industry organizations in Tasmania and South Australia. The current funding of the breeding program is obtained from royalties associated from sale of genetically improved material, contributions from shareholders and federal R&D grants. Operations are coordinated by a management group consisting of two people, and the ASI's Board of Directors is largely constituted of farmers serving voluntary in the board and without economic compensation.

ASI was established in order to make the breeding program activities economically self-sustainable and not reliant on external funding. In the original plans this was to be achieved by a combination of increased market penetration with the genetically improved material and a gradual increase in the mandatory royalty fee for use of this seed. For reasons discussed below this has not been achieved, and the current business structure for ASI must therefore be changed in order to secure that the breeding program activities are sustained for the benefit of the entire Pacific Oysters sector in Australia.

The Pacific Oyster industry has received substantial public grant funds for establishing its current genetic improvement program. At this point it is important that all players in the industry realize that the sector's long term viability heavily depends on use of a high performing stock developed through a well-designed breeding program such as the one that is now established. Hence it must be recognized that sustaining the breeding program is a shared responsibility by the entire sector, and that a funding model should be established in which all levels participate. Customers paying a premium price for access to genetically improved material are usually the main source of funding for breeding programs following an initial period of public funding. It should be noted that it is highly unlikely that lines developed by simple mass selection schemes by individual hatcheries will be offering high performing seed over the long term.

Breeding program

With the modifications implemented following the suggestions and recommendations described in the final report from Project No. 2006/227 "Enhancement of the Pacific Oysters selective breeding program", ASI now operates a well-designed and effective family based[2] breeding program implying that breeding candidates are ranked according to a combination of their own performance and the performance of their close sibs. The breeding nucleus is always reproduced with a new unique set of families produced by crossing primarily unrelated selected breeders, which in turn are performance tested and producing new breeding candidates to continue the selection cycle.

[2] . It should be noted that the term "family lines" commonly used in describing improved lines produced in these programs does not imply that individual families are reproduced over several generations.

With a capacity for annual production of approximately 50 pedigreed nucleus families by single pair matings (strip spawning) and extensive performance testing for key traits of economic importance across relevant production areas in Tasmania significant improvements can be expected. The current program design and methodology used for estimation of genetic parameters and breeding values and for derivation of relative economic weights for the individual traits is in line with the international industry standard for multi-trait selection work in aquaculture species, facilitating long-term sustained improvements in the breeding nucleus population and allowing for close monitoring and safeguarding against unfavorable correlated responses. Likewise the implemented design offers excellent possibilities for production of dissemination lines which can be structured to meet the shorter-term needs for the Australian Pacific Oysters sector, both with respect to production traits as well as survival and resistance to specific diseases (e.g. POMS).

Dissemination and marketing

The target sectors for the program are Tasmania and South Australia. Genetically improved material resulting from the ASI program is currently disseminated to the end-users mainly via two collaborating Tasmanian hatcheries serving as multipliers. In addition one hatchery in South Australia has been producing, apparently with low success, dissemination seed as well. The two Tasmanian hatcheries, which combined account for approx. 80% of the total hatchery production of Pacific Oysters, are offering the ASI material in direct competition with their own mass-selected material, and at a higher price due to a mandatory royalty collected on behalf of ASI. One of the main multipliers is also producing and selling triploid seed, based either on their own mass selected line or on ASI families. No benchmarking data for the alternative materials are currently available. ASI provides collaborating hatcheries with selected broodstock for multiplication free of charge, but multipliers are collecting the mandatory royalty fee for use of the selected line from the end users on behalf of ASI. In the current arrangement ASI is responsible for marketing the genetically improved material to the end-users.

Funding situation

The current annual operating cost of ASI is indicated at approx. AUD 280,000. At present income from royalty on sales of genetically improved material is only around AUD 80,000 and the deficit is currently covered from R&D grants and direct contributions from ASI's owners. It was originally expected that the royalty income over time should cover most of the operational costs of the breeding program, based on initial projections of production volumes and an expected rapid uptake of the selected material in the industry. However, the current use of the ASI material in Australia has remained low, at present likely below 20% of the national demand for spat. In addition to the issues discussed below, the initial market penetration was also severely hampered by early release of seed from the breeding program with poor shape/condition characteristics, resulting from the strong selection initially done for rapid growth without properly understanding the unfavorable correlated response expressed in shape/condition. The current testing and selection scheme has corrected for this.

Main challenges with the current commercialization model

There are a number of challenging issues regarding the current business model for ASI:

- Under most farming conditions the selected line is yet not clearly outperforming alternative materials which are offered at lower price (i.e. without mandatory royalty).
- The assigned multipliers are marketing and selling their own mass selected lines in competition with the ASI line.
- ASI is in a weak position to effectively market the selected material to the sector in competition with the hatcheries promoting their own lines. The hatcheries also benefit from customer loyalty developed over the longer term.
- The ASI brand is presently tarnished in South Australia due to quality issues with recent spat produced and sold there.
- ASI's role is not clearly focused. Current responsibilities cover a wide range of tasks spanning from core breeding program activities (including annual reproduction of the breeding nucleus, larval rearing, nursery rearing, performance testing, data recording and data management, coordination of genetic evaluations and documentation of genetic gains, provision of selected stock to the multipliers, etc.), through to the marketing of the genetically improved material in the end market.
- With only two employees, ASI is clearly under resourced to undertake all of its current tasks.
- The current budget appears not to fully reflect true costs. Current breeding programs operations partly funded/subsidized with on-going R&D project.

Alternative business model
The current business model for ASI is obviously not viable in the long term, and puts the breeding program at risk. An alternative model should be assessed, in which ASI's role is more clearly focused on core breeding program activities and funding secured from a larger segment of the industry. Securing a soundly operated and effective breeding program is essential for long term sustainability of the entire sector, to which all players should contribute.

The following principles are proposed as a basis for a new business model:

- ASI limits its role to become provider of genetically improved material to accredited hatcheries serving as multipliers. These should include the two collaborating hatcheries that are currently accounting for most of the hatchery reared Pacific Oyster spat produced in Australia. Additional hatcheries may be accredited to ensure access to improved seed throughout all regions of production.
- ASI runs the family based breeding program, and ensures that nucleus selection is facilitating long term needs (reflected in broad selection goal), and controlling long term accumulation of inbreeding in the selected line.
- ASI establishes and maintains effective data recording and data management system for the breeding work (and disseminated lines).
- ASI contracts quantitative genetic expertise on a long term basis for genetic evaluations and breeding value estimations, and access to genetic support for

day to day breeding decisions. This is a critical competence base for any selective breeding operation.

- ASI establishes effective communication with the collaborating hatcheries and growers to ensure that selection priorities in the breeding nucleus and for production of dissemination lines are in line with the sector's long and shorter term needs, respectively
- ASI facilitates testing of the accredited hatcheries' current mass selected lines (if applicable) along with the regular performance testing of the nucleus families. These benchmarking data are made available to the hatcheries as basis for optimal replacement/upgrade of the respective hatcheries' dissemination lines. Furthermore material from current mass selected lines developed by the hatcheries could be incorporated into the breeding program if their relative performance warrants it, in order to further broaden the genetic base in the genetically improved stock.
- The current ASI selected line is no longer branded as separate product in the end market.
- ASI develops and maintains long term agreements for access to breeding nucleus facilities, for performance testing, for conducting controlled challenge testing, etc.
- ASI coordinate R&D projects relevant for further development of the breeding programs (investigation of new traits, etc.).
- The hatcheries are entitled to incorporate the genetically improved lines into their marketed products according to their own priorities.
- The current mandatory royalty for genetically improved seed is abandoned and is replaced with a system ensuring that all seed sold through the accredited multipliers serves as funding base for the breeding program. This royalty is to be paid to ASI by the multipliers, who in turn compensates by increasing the price of their spat. This represents a significant increase in funding base for the breeding program. Royalty level needs to be decided based on the true operational cost of the breeding program.

The structure of the new business model needs to ensure that all segments in the sector contribute to the new funding model. In principle this also includes the accredited multiplier hatcheries in case the ownership of the nucleus material is maintained by ASI and not transferred to the hatcheries. Contributions from the multipliers may be in the form of an annual license fee or an initial one-time fee upon signing into the new model. However, as the hatcheries eventually will have to carry that cost onto their sales price, it is likely a simpler arrangement to incorporate the multipliers' contributions to the breeding program in the overall royalty payment to ASI.

The benefits for the accredited multipliers are several:

- "Exclusive" rights to freely incorporate the selected material into their respective products.
- It secures the multiplier hatcheries' long term access to genetically improved and high performing materials. It is not likely that the performance of the hatcheries own mass selected lines can be maintained over time due to accumulation of inbreeding.

- Strong influence over trait prioritisation and selection decisions within ASI's breeding program based on access to individual trait EBVs for candidate families and predicted genetic gains for alternative scenarios provided by ASI.
- Freedom for selection of relative weights for dissemination material which should reflect the shorter term priorities for the end-users of the spat. These would be expected to deviate from the broader, long term selection priorities set forth for the breeding nucleus. This applies to each of the multipliers separately, and leads to increased diversification of product portfolio.
- Access to include their own mass selected lines in the performance testing done for nucleus seed, providing internal evaluation for optimal replacement strategy in commercial products.
- Avoids competition with ASI brand in the market.

ASI should prepare a 3-year detailed budget and cash flow analysis for the core breeding operation (not including additional R&D activities) as basis for realistic assessment of funding needs. These numbers need to be transparent and agreed upon by the sector members.

Risks

Implementation of the new model is not without significant risks.

- To ensure an adequate funding base for the operation, it is critical that at least the two major hatcheries join in as accredited hatcheries in the new model. If one of these decides not to participate and maintains sales of their own mass selected material to a loyal segment of end-users in competition with the genetically improved seed, this will effectively block the efforts to maintain an effective and powerful breeding program for the long term benefit for the Pacific Oyster sector.
- Secondly, opportunistic hatcheries outside the system can compete on price and win market shares with alternative seed not originating from the breeding program. This will erode the funding base for the breeding program. Although this risk should be considered to be temporary as most end-users will request genetically improved seed as the breeding program progresses, it may represent a short term challenge. Increasing the number of licensed multipliers may be considered to reduce this risk. To reflect the preferential status of the current multipliers, as separate license fee may apply for hatcheries entering at a later stage. Exact terms must be determined reflecting the overall funding model chosen.
- Lack of skilled technical personnel to coordinate and run the breeding program operations.

Governance

The ASI operations must be professionally governed. The constitution of the board of directors will likely need to be changed reflecting ASI's new business model and possibly changed ownership and/or legal status. The board should be manned according to competence and skills needed for professional operation of ASI, to ensure that board decisions are reflecting ASI's rather than the individual shareholders' interests. It is strongly advised the chairman of the board is paid for his or her services and recruited from outside the oysters sector, in order to ensure focus on sound governance and priorities serving ASI long term needs. Although this will add some financial strain to the operation, it is essential for the long term success of ASI's business model. The chairman of the board must also play a leading role in the process of selling in ASI's new business model to the sector.

4. SYDNEY ROCK OYSTERS

Status of the breeding program
A breeding program for Sydney Rock Oysters (SRO) was initiated in the early 90's, with base materials obtained from local stocks from several regions in New South Wales. The program initially targeted fast growth based on performance testing in Port Stephens and three locations in Georges River, and increased resistance to winter mortality (WM). Since 1997 focus has shifted to also include selection for increased resistance to the QX disease, based on testing in affected areas. Both WM and QX are caused by protozoan parasites, and the F2-F4 (current) generations are developed after subsequent testing in areas affected by WM, QX or both. The selection work to date has mainly been based on mass selection. At present approximately 120 full-sib families have been produced and now constitute the basis for further selection.

The breeding program is operated by the Select Oysters Company Pty Ltd (SOCo). SOCo has no hired management team, and the company's activities are administered by its Board of Directors serving on a voluntary basis.

The selection program for SRO conducted by the Port Stephens Fisheries Institute (PSFI) has produced highly significant and impressive results in terms of improved growth rates and in particular for increased disease resistance for WM and QX in the selected lines. The research work at PSFI has also developed hatchery technologies of high relevance for effective selection work. Strip spawning (mating of single pairs of breeders) is now done consistently in the breeding nucleus, and facilities have been developed for simultaneous production and initial rearing of a high number of pedigreed families. Likewise, a system is established for extensive performance testing of these family lines at several locations affected by WM, QX or both.

This represents an excellent platform for full implementation of a highly effective family based, multi-trait selection program for SRO. Such program will facilitate breeding decisions to be taken on basis of estimated breeding values (EBVs) based on quantitative genetic modeling taking into account the full genetic relationships among the families produced and performance tested, while at the same time maintaining the accumulation of inbreeding at an acceptable level in the selected population. This is essential for running an effective and sustainable breeding program over the long term. Likewise the program structure facilitates production of dissemination lines in line with the short term needs for the SRO sector.

Major challenges
Compared to the situation for Pacific Oyster, the situation for the Sydney Rock Oyster breeding program is significantly different with respect to two major issues with relevance to commercialization:

1. Lack of consistent production capacity for high volumes of hatchery produced spat is severely obstructing efficient transfer of genetic gains obtained in the breeding program to the sector. At present there is no consistent demand for hatchery reared spat with a large segment of growers who consider that "free" wild caught spat is performing equally well, and the one commercial hatchery offering this product is not consistently meeting even the limited current

demand for hatchery reared spat in the sector. The PSFI research hatchery meets surplus demand with spat from its selected lines where it can, but is also unable to produce commercial quantities on a regular basis. Lack of hatchery technology and high volume spat production from selected material is obviously a major constraint for sector wide use of genetically superior lines in the commercial production and to make the industry less dependent on extensive use of wild spat.

2. The breeding program for SRO is currently not structured to take full advantage of the possibility for effective family based multi-trait selection. This will require implementation of a proper breeding plan developed in a solid quantitative genetics context. Selection decisions are not yet routinely based on estimated breeding values derived from quantitative genetic analyses based on all relevant data accumulated in the program, which is essential for meeting the long term needs and priorities for the commercial SRO sector. There is also a dependency on other on-going R&D activities at PSFI to facilitate the reproduction of the family lines.

On this background it is not realistic that the program can be fully commercialized and made economically self-sustainable in the short term.

For long term sustainability, the industry needs to focus on the following:

- Development of a reliable hatchery technique for consistent high volume production of SRO spat, and a reliable source of supply which preferably should be a commercial hatchery. This is critical for allowing the industry to change from largely relying on wild caught spat to a more sustainable and cost effective production based on use of domesticated and genetically improved seed.
- Complete the process of restructuring the breeding program in order to facilitate effective family based multi-trait selection following the international industry standard for genetic improvement of aquaculture species. This requires extensive quantitative genetic competence and implies:
    - Preparing an operational breeding plan based on sound quantitative genetics and selection theory, which defines the long term goals for the nucleus. The selection as well as the shorter term priorities for the dissemination material. The plan should describe: the nucleus design and operations, performance testing scheme, the system for data recording and storing, quantitative genetic analyses of estimation of genetic parameters and breeding values estimations facilitating effective multi-trait selection, etc. The breeding plan should also detail the dissemination strategy for transfer of the genetic gains in the breeding nucleus to the commercial SRO sector in Australia.
    - Establishing effective data recording (nucleus and performance testing) and database management systems. The database should include all relevant pedigree and performance data recorded till date. Access to these is essential for breeding value estimation and regular updates of genetic parameters such as heritabilities and genetic correlations.
- To ensure that the selection program is developed in line with the sector's long term needs and priorities, it is recommended that the breeding program

activities are coordinated and led by the SRO industry. As the industry owned breeding company, SOCo should be driving this process. To be able to undertake this role it is recommended that SOCo hires a management team with the core responsibility to coordinate the breeding program activities, in close collaboration with the key PSFI personnel, and with technical input from a competent provider of quantitative genetic services (e.g. CSIRO which already is provider of such services to the PO program).

- On the longer term SOCo management team needs to undertake basically the same task as those earlier specified for the management of the breeding program for Pacific Oysters.
    - It needs to secure long term access to facilities and skilled manpower to conduct breeding nucleus and performance testing operations.
    - Agreements securing long-term access to quantitative genetic competence for routine data analysis and breeding value estimations, support selection decisions in breeding nucleus and dissemination, etc. Reflecting the highly dynamic nature and complexity of operating multi-trait selection programs, it is critical to have access to quantitative genetic competence on a regular basis for effective and safe execution of the breeding program.
    - Effective communication between the breeding program operations and the intermediate (i.e. at least one multiplier) and end users of the seed in the sector. Such communication is fundamental for securing that selection decisions made in the nucleus are in line with the long-term priorities (and safe guarding) for the sector, and likewise that the production and dissemination of commercial seed to the end users is optimal with respect to shorter-term priorities and challenges.
- The points addressed regarding the governance structure of ASI also applies to SOCo. A sector driven breeding program must have professional governance, guided by board of directors appointed by the shareholder so that required expertize is secured in this body. It is highly recommended that the board of directors is headed by an external chairman, who is independent of the breeding company's shareholders. An active board is also essential for effectively working with the sector to ensure sector commitment to the breeding program and wide uptake and use of genetically improved material.

As basis for a realistic assessment of the funding needs for the SRO breeding program, SOCo should prepare detailed 3-year operational and cash-flow budgets for the operation. As for Pacific Oysters, these budgets should reflect actual costs associated with the core breeding program activities, without including R&D that presently directly or indirectly subsidises the breeding program operations. R&D activities may alternatively be specifically budgeted but clearly separated from the issues related to core breeding program operations. These budgets must be transparent and agreed upon in the sector, and used to detail funding needs which realistically have to be secured from the private sector or public sources.

In the absence of an effective commercial partner SOCo also needs to develop or promote the development of commercial hatchery capacity to multiply the improved oyster. It is likely that the program will require on-going support (in kind services and seed supply) for an interim period of several years before a robust commercial hatchery capacity is developed and a cost recovery funding model is developed and implemented

Coordination across oyster programs
Operational tasks are highly overlapping between the two oysters breeding programs, and there is scope for substantial synergies and cost savings if activities are coordinated and run by the same organization and/or management team. In particular this applies for the data recording and database management systems (which is already in place for Pacific Oyster), and both programs could also benefit from using the same provider of quantitative genetic services. Coordinated subcontracting of quantitative genetic services across programs may also provide improved services, as the total service volume increase making it more attractive for competent providers to further develop and extend its level of services. Geographical distances, different ownerships, and different funding models for the individual programs may however present some significant challenges to extensive coordination between the two programs.

5. BARRAMUNDI

Commercial farming of Barramundi (also known as Asian sea bass) in Australia has been done for more than two decades, and is now considered as an established aquaculture industry in the country. The current annual production is estimated to around 5000 tons, and the annual fingerling production in the range 3-5 millions. The main production regions are North Queensland (~70%), Northern Territory and Northern Western Australia, where Barramundi is farmed in diverse production systems (freshwater ponds, brackish water ponds, saltwater raceways, and in cages in the sea). Some smaller scale production is also done in recirculation systems in New South Wales and South Australia.

The Australian Barramundi industry is facing significant challenges related to high production costs (primarily due to high labour costs and significant costs associated with managing environmental regulations) on the one hand and intensifying competition from imported Barramundi produced in South East Asia on the other. Extensive R&D work co-funded by the Barramundi sector through ABFA has clearly shown that selective breeding is the most effective way to improve yield and reduce production time which would significantly reduce the cost of production of the farmed Barramundi, the key factors affecting the profitability in the industry. A well-resourced breeding program for the species is already established in Singapore, which may further complicate the situation for Australian Barramundi farmers as future imports may be even cheaper.

Hatchery technology for reproduction of Barramundi in captivity (natural spawning with communal stocking of male and female breeders) and larval culture is relatively well established. The industry is currently supplied with fingerlings from a number of independent hatcheries, which are individually operating their own broodstock derived from wild caught breeders recruited from different areas along the northern coasts of Australia. Due to limited infrastructure and to some extent lack of genetic expertize, the domestication processes carried out over several generations by individual hatcheries have tended to recruit new generations of broodstock from a low number of parents without tracking of pedigrees and monitoring genetic relationships in the populations. This procedure will inevitably lead to rapid increase in inbreeding levels and loss of genetic variability in the domesticated lines, expected to result in reduced fitness and genetic production potential in the fingerlings produced.

It is now widely accepted throughout the Barramundi sector that the establishment of an industry wide genetic improvement program is critically needed to ensure the Australian industry's long term sustainability. Over the last years, several Australian Seafood CRC projects co-funded by the Australian Barramundi Farmers Association (ABFA) have assessed alternative options for implementation of a breeding program for the Barramundi sector and demonstrated that even a basic well-designed program will have highly favorable benefit-cost ratios in the range 11:1 to 16:1 after 10 years with an internal rate of return between 25% and 65%.

These projects have also identified and discussed the main biological risk factors and constraints that may prevent successful implementation for a semi-mass spawning species like Barramundi, and demonstrated how these can be adequately handled in the proposed breeding program structure. Furthermore the research has shown that a centralized model with one dedicated facility operating as breeding nucleus is the preferred model both with respect to biological efficiency, and from a cost and biosecurity point of view.

Status

Based on the work referred to above, an initial business case for a national breeding program was prepared under the Seafood CRC and later endorsed by the sector as the primary industry plan. Following the main elements laid out in the business case proposal, ABFA has finalized a business plan for an industry owned not-for-profit national breeding entity (Barratek) to run the breeding program and to produce genetically improved Barramundi larvae and juveniles to the industry. Barratek will be managed by a Board of Directors largely derived from the ABFA members. It is expected that the majority of the national Barramundi hatcheries will participate in the program, with combined production expected to cover more than 80% of the Australian fingerling production. Nearly all major producers have indicated that they would prefer genetically improved fingerlings from a national breeding entity, and some indicated that they would prefer to close down own hatchery operations if reliable supply of quality throughout the year from a central entity could be ensured.

Funding structure

The establishment cost for the breeding program is minimized through leasing arrangements for facilities and in-kind support from ABFA members. Since the program will have minimal income from sales of improved seed during the initial years of operations, the current project funding plan laid out in the Barratek Business Plan is counting on an external grant funding of AUD 5 million over five years to avoid that the breeding program becomes prohibitively expensive during the initial years. The external public funding is not yet secured and there has been no active discussion among the industry about industry derived funding for the program.

Technical/biological issues

- Technically the Barratek initiative is solidly underpinned with extensive documentation of the Australian Barramundi industry's need for a selective breeding program and how a cost-effective and bio-secure program should be structured and practically implemented.
- A family based breeding program dimensioned for annual production and performance testing of 50 families per generation as proposed should be considered as a critical minimum even for a program aiming at improving growth as the single target trait. If the breeding goal is extended to include additional traits (e.g. carcass quality traits or disease resistance) the number of families in the program will likely need to be increased to obtain selection responses at acceptable levels for accumulation of inbreeding in the selected population.
- The key relevant biological risk factors for a Barramundi breeding program are identified and discussed, and it is to be concluded that none of these pose a major threat to the successful implementation of a selective breeding program.
    - The fact that Barramundi first matures as males and later differentiate into females is not representing a major problem in a family based program facilitating tracking of complete pedigrees in the nucleus population. A highly successful family based selection program for gilthead sea bream (*Sparus aurata*), another species with the similar

sexual maturation pattern, has been operating for more than 10 year in Greece.

  - The recent findings from the pilot scale trial of synchronized spawning among communally stocked male and female breeders (Seafood CRC project 2009/730) showing that almost all breeders contributed to the spawning event on a given day are very important. This is a highly critical factor for successful implementation of a breeding program design as laid out in the current plans.
  - Production of single pair matings by artificial stripping might potentially significantly improve the efficiency and reduce risks for a family based breeding program for Barramundi by providing means of ensuring a better balanced family representation among the animals reared for performance testing and/or as future breeding candidates. To facilitate this, however, offspring groups from each single pair mating must be reared separately through initial periods with high differential mortalities, followed by subsequent pooling for testing. This would require some additional infrastructure (smaller incubators/tanks) at the breeding center, and procedures for standardizing rearing conditions between tanks. It should be noted that single pair mating following artificial stripping of male and female breeders is now done routinely for reproduction of breeding nuclei in family based programs for other farmed marine fish species such as Atlantic cod (*Gadus morhua*), European sea bass (*Dicentrarchus labrax*) and the gilthead sea bream. These are all species for which standard hatchery production of eggs is done by natural spawning following communal stocking of male and female breeders, as the case is for Barramundi.
  - Production of families by artificial stripping could potentially also significantly reduce operational costs and increase flexibility in the breeding program. If families were reared separately until the fish reached a size allowing for use of physical tags (e.g. min. 10 grams for PIT tags), DNA fingerprinting would not be required for parental assignment. The choice of method for tracking pedigree in a family based breeding program for which families can be reliably produced by artificial stripping primarily relies on a benefit/cost analysis considering the additional infrastructure and work needs vs. the cost of recurrent DNA fingerprinting and the risks associated with highly variable family sizes. The majority of family based fish breeding programs are currently using physical tags for tracking pedigrees. It should be noted that the positive results reported on the participation of individual breeders in the pilot scale trial of synchronized spawning (project 2009/730) indicate that single pair matings by artificial stripping may be feasible for Barramundi.
  - The assessment of the possibility for single pair matings in Barramundi and alternative use of physical tags for tracking pedigrees can be done later when more experience from nucleus operations is gained and should not further delay the initiation of the selective breeding program in accordance with the proposed design.

- The strategy of operating the breeding program with one central breeding nucleus facility is strongly supported. As pointed out in the background documentation, an alternative design requiring synchronization and coordination of activities related to family production and performance testing across hatcheries/farms would obviously be challenging and costly, and also carry significant risks for occurrence of events that may dramatically reduce the efficiency of the selection work. Likewise, balancing long-term breeding program needs and shorter term commercial production priorities in the same facility are proven to be very difficult in most situations. Breeding program activities are also highly specialized and hence needs dedicated and skilled personnel, which are best secured at a dedicated central facility.

- A highly relevant issue relates to need to operate with stringent biosecurity. Following the initial stage with introduction of a genetically diverse collection of mature breeders to serve as the base population for the breeding program, the operation of a centralized breeding nucleus can be operated with limited introduction of animals from outside the facility, and hence with a very high biosecurity level. The need to maintain the highest health standard in the breeding nucleus is of key importance for any breeding program.
- To manage biosecurity risks, it is recommended that future breeding candidates are reared and performance tested at the breeding nucleus facility itself, which can easily be facilitated at the GFB facility chosen for this purpose. Selection decisions can then be made based on the performance of individuals at the breeding nucleus and the performance of their siblings on farms. Based on experience from a number of other family based fish breeding programs, the risk that this should lead to the development of a "laboratory super fish" that are performing excellently at the breeding center facility and not in other commercial environments is minor, even if commercial production takes place in a range of distinct production environments. Substantial GxE effects are seldom seen for fish species, and in family based breeding programs breeders are in part selected based on the performance of sibs tested across commercial production systems.
- Considering the broad range of commercial production environments for Barramundi in Australia, the magnitude of possible GxE should be investigated in the early stages of an industry wide breeding program for the species. This could most cost-effectively be done by performance testing the first batch of nucleus families across relevant grow-out systems (including the regular grow out ponds at the breeding nucleus site), which would provide relevant data for assessment of GxE effects in addition to serving as basis to rank the first generation of breeders for nucleus selection. The results of the GxE analysis would determine whether future testing of families should be done in multiple production environments in order to ensure satisfactory selection response across all production systems.
- The proposed strategy for constructing the base population for the program is sound. For most programs securing a genetically wide base population is done by collecting base animals from as many sources of domesticated and/or wild populations as possible. In the present case with Barramundi, the genetic diversity in the breeding nucleus can be further optimized based on the extensive broodstock characterization done in Seafood CRC project 2009/730. If wild fish is available from known stocks not represented in the current hatchery stock, it is recommended that some of these are also used in the base population for the breeding program.
- The Good Fortune Bay facility outside Bowen which was visited during my visit to Australia seems ideally equipped to serve as the central breeding

nucleus facility for the program. The facility has extensive infrastructure available, and experienced and motivated hatchery staff.

Issues related to organizational structure and funding

- The alternative organizational models for establishing and operating a selective breeding entity are broadly analyzed in several parts of the background documentation provided for this review. The final report from the Seafood CRC project 2009/738 addresses all relevant issues and realistic options regarding business and ownership structure, alternative remuneration models, management structure, and commercial business risks. Based on the assessments in that report and extensive discussion with the industry players, a recommended structure is described in detail in the Barratek Business Plan (Nov. 2011).
- The proposed business structure recommended in the Barratek Business Plan should well serve the purpose of establishing a cost-effective breeding program for Barramundi, which can be further streamlined and optimized to meet the future needs for the Australian Barramundi sector. It may also, as indicated, 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. However, export of improved seed might potentially make imports to Australia even cheaper over the long term.
- 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). This is clearly shown in the Barratek Business Plan. At the same time it is evident that the sectors critically needs to implement a selective breeding program to be able to significantly reduce production costs and stay competitive in the long run, which is fundamental for the sustainability of the industry. This should be clearly communicated to potential public funding sources.
- Considering the urgency of the issue, the Barramundi sector should be prepared to develop an alternative funding model in case the requested level of public funding will not be accessible. It should be realized that the current national hatchery capacity appears to be well above the required capacity and procedures are not likely to be sustainable over the long term, and timing is critical. The process of producing genetic improvement inevitably takes time, and each year without a well-designed breeding program in place is further delaying the industry's access to the significant and critical benefits that such program will provide for the sector.

Recommended actions

The need for a breeding program and how it could be effectively structured has been discussed in the Barramundi sector for many years. 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.

6. PRAWNS

It should be noted that no background information about the prawn programs was provided for this review. The comments given in the following are therefore of cursory nature, and mainly based on brief conversations with industry representatives (Alistair Dick, Pacific Reef; Tony Charles, Australian Prawn Farms; and Nick Moore, Gold Coast Marine) and Nigel Preston, CSIRO.

Australia has over the last years established a small but significant commercial production of Black Tiger prawn, *Penaeus monodon*. At present, the combined production in the Australian prawn sector is closing in on 5,000 tons. The industry is currently undergoing consolidation; some farms are leaving the sector and leasing their ponds to others. Due to strict environmental regulations, there has not been granted new concessions in the country for many years. These policies are not expected to change, at least not in the short term.

Black Tiger Prawn production dominated the Asian and hence the world's production of farmed crustaceans for many decades, but has in recent years largely been replaced by Whiteleg shrimp, *Litopenaeus vannamei*, a species native to the tropical Pacific coastal waters of the Americas. The rise of importance of the *L. vannamei* from an estimated 10% of the world production in 2000 to 75% in 2008 is attributed to many factors including ease of reproduction in captivity and hence the ability to close the reproductive cycle and produce genetically superior and higher health seed, rapid growth rate, lower protein requirements, tolerance to high stocking density and tolerance to low salinities and temperatures. Representing a closed thelicum species, commercial farming of *P. monodon* has traditionally largely been based on seed produced from wild-caught breeders.

In collaboration with CSIRO, three Australian prawn farming companies have made substantial progress towards effective domestication of *P. monodon*. 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 are in different stages. The most advanced program (run by Gold Coast Marine Aquaculture - GCMA) is currently working with the F10 generation of their domesticated line, while the two other programs (operated by Pacific Reef and Australian Prawn Farms) are less advanced, having completed up to 5 generations of domestication.

It is obvious that the most important benefit from the Australian work with *P. monodon* is the ability to more successfully reproduce the animals in captivity and hence close the reproductive cycle of the species. This has been tried by many other groups in recent years with limited success, putting the successful Australian programs in a fairly unique position internationally, although it is acknowledged that there are still some challenges in obtaining adequate numbers of progeny from the domesticated broodstock.

Successful reproduction of captive prawn paves the way for effective domestication of the species, and eventually opens for implementation of effective selection programs. It is noted that the Australian programs have produced very significant changes in the domesticated stocks, in particular with respect to increased growth rates and improved feed conversion efficiency. On the other hand the reproductive capacity of the domesticated lines is still significantly inferior to what can be obtained with wild broodstock, and their reproductive reliability is low. It is indicated that male fertility seems to be a major issues, and for this reason wild males are still routinely incorporated into the domestication lines which is slowing down the domestication process and any genetic improvement going on.

The low reproductive success of the domesticated lines is substantially increasing infrastructure and operational costs for the commercial production, since much higher number of breeders needs to be kept and matured to ensure availability of enough seed for stocking the ponds in the critical time window.

Furthermore, the lack of reliable reproduction of the domesticated lines is significantly limiting the possibility to implement an effective selection program as the on-farm breeding decisions are largely commanded by availability of mature breeders ready to spawn rather than on genetic merit of the breeding candidates based on extensive performance testing and accurate breeding value estimates for key traits of economic importance. On this background it is assumed that the core elements of the on-going programs relates primarily to health screening and use of genetic markers to avoid rapid accumulation of inbreeding in the populations undergoing domestication.

It is evident that the development of an effectively domesticated population of *P. monodon* would carry a tremendous commercial potential for companies controlling these lines. In spite of the dramatic rise of *L. vannamei* production in the region, major shrimp producing countries throughout South East Asia would be expected to rapidly increase their monodon production if a reliable source of domesticated and improved high quality seed could be secured. In the current situations, however, all three companies working with their respective lines under domestication are struggling to produce enough seed to stock their own ponds, and commercialization of their lines is likely not the short term focus. There is also a risk of a hiatus in the development of on-going breeding programs at Pacific Reef and Australian Prawn Farms due to the absence of project funding whereas the development of the program at Gold Coast Marine Aquaculture is being significantly privately resourced.

Considering the high costs associated with developing a sustainable domesticated line of *P. monodon*, it is surprising that the three on-going programs appear to be run independently. It is informed that the GCMA program is producing 20-30 families per generation (no details are available for the other two programs). If the domestication program is kept closed without introduction of new breeders from outside, the inbreeding level after 10 generations is expected be significant and expected to further increase rapidly even if the base population was genetically diverse and mating of close relatives has been avoided during the initial generations. However, if new genetic diversity is routinely introduced from wild stocks (as indicated for all the programs) this would slow the rate of inbreeding accumulating in the target line, but at the same time also reduce the efficiency of the domestication process and even more so any efforts of systematic genetic improvement beyond domestication.

From this point of view it is evident that collaboration involving exchange of material between the three programs could increase the effective population size for all programs, and hence speed up the domestication process and increase the genetic base securing their longer term sustainability. Access to breeders from the GCMA program representing material in a more advanced stage of domestication may be considered a larger benefit for the two other companies as compared with the reverse transfer of animals, but GCMA would under any circumstance benefit from introducing new animals from another domestication program rather than from the wild.

In view of the commercial value of domesticated lines of *P. monodon*, it is assumed that IP rights to the lines are addressed and defined in the contracts between CSIRO as the service provider and the individual companies involved.

7. GENERAL CONSIDERATIONS

The aquaculture industry in Australia is highly diverse and fragmented. With the exception of the Atlantic Salmon industry in Tasmania, aquaculture production is characterized by small production volumes and high production costs. This is posing a significant threat to the sectors' long term economic viability. The potential for industry growth for all sectors is also severely restricted due to tight and stringent environmental regulations in the country. 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 production in the country.

Of the species considered in this review, a well-designed family based breeding program is being implemented for the Pacific Oyster but without a viable long-term funding structure yet in place. For Sydney Rock Oysters and Barramundi similar programs are under planning. Smaller scale production in Australia is also established for other aquaculture species such as abalone and prawns. For prawns three separate in-house domestication/ breeding programs are operated by individual prawn companies which all are provided core genetic services from CSIRO through individual contracts. CSIRO is also providing genetic services to the Saltas breeding program for Atlantic salmon in Tasmania, which represents the largest scale breeding program in Australia.

It is widely recognized that the implementation of cost effective selection programs plays a key role for the long term sustainability of aquaculture production, as they are critical for obtaining significant and sustained reductions in production costs. The on-going and planned selective breeding programs in Australia all critically depend on long-term access to core quantitative genetic competence for program design and operational tasks related to database management, statistical modeling and breeding value estimations, inbreeding control, documentation of genetic changes, and for structuring optimal dissemination of improved material to the target sector, and some also depend on DNA fingerprinting services pedigree reconstruction. The main elements of these inputs are largely the same across species, and there is obviously a significant potential to generate cost saving synergies by utilizing a common competence base and data management system (with minor modifications according to the program structure of the individual program).

It should be noted that few aquaculture breeding companies worldwide, even in established high volume industries like Atlantic salmon, are covering their need for core genetic services with in-house resources. This is in part reflecting the highly specialized nature of these services, and scarce availability of skilled and experienced personnel with the critical skills. The complexity and dynamics of advanced selective breeding operations is also suggesting that access to a critical mass of expertize in these areas is needed to secure the quality of these services over the long term.

Overall, 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. It is evident that at least for some of the Australian programs, R&D funds are currently being used in direct or indirect subsidy of what could be provided as commercial services. This may potentially slow down the progress of genuine R&D work that could be adding value to current and future breeding programs.

APPENDIX I: BACKGROUND MATERIALS

Pacific Oysters

- Final Report Project No. 2006/227
- Administrative summary and progress report "Incorporation of selection for reproductive condition, marketability and survival into a breeding strategy for Sydney Rock Oysters and Pacific Oysters"
- ASI Business Plan Summary 2012

Sydney Rock Oysters

- Final Report Project No. 2006/226
- Bunter, 2007. Technical Evaluation of the SRO Breeding Program
- OGCORP, 2007. Report on Business Strategy for development and delivery of multiple breeding stocks for Select Oyster Company (SOCo)
- Administrative summary and progress report "Incorporation of selection for reproductive condition, marketability and survival into a breeding strategy for Sydney Rock Oysters and Pacific Oysters"

Barramundi

- Final Report 2008/758
- Final Report 2009/738
- Project Milestones Report 2009/730 (6/29/2012)
- Barratek Prospectus
- Barratek Business Plan (Nov. 2011)
- Seafood CRC Concept Assessment "Performance of Barramundi from widespread genetic sources in diverse grow out environments"
- Administrative summary "Development of Barramundi selective breeding entity II"

APPENDIX II: ITINERARY

Mon September 3., Adelaide

- Seafood CRC:
    - Len Stephens, Graham Mair

Tue September 4., Cairns

- Australian Barramundi Farmers Association
    - Chris Calogeras, Desiree Allen., Marty Phillips, Ken Chapman. and Bob Richards

Wed September 5., Townsville

- Justin Forrester, Good Fortune Bay hatchery (Bowen)
- Dean Jerry, JCU (with Graham Mair)

Thu September 6., Townsville

- Australian Prawn Farmers Association (with Graham Mair)
    - Allistar Dick (Pacific Reef), Tony Charles (Australian Prawn Farms)

Fri September 7., Port Stephens (with Graham Mair)

- Wayne O'Connor and Michael Dove (PSFI),
- Ray Tynan and Tony Troup (SOCo)
- Scott Parkinson, Shellfish Culture

Mon September 11., Tasmania

- Matt Cunningham, ASI
- Ben Cameron (Cameron of Tasmania)
- Nick Elliot and Peter Kube, CSIRO R&D

Tue September 12., Tasmania

- Hayden Dyke
- Scott Brooks
- Matt Cunningham, ASI

Wed – Thu September 13-14., Melbourne (by phone)

- Rachel King, Australian Oysters
- Gary Zippel, ASI
- Nick Moore, Gold Coast Marine
- Nigel Preston, CSIRO
- Nick Robinson (in person)

Fri September 14, Melbourne (by teleconference)

- Debriefing Len Stephens and Graham Mair, CRC

[Wed September 19, Sunndalsøra (by teleconference)]

- Debriefing with representatives of Oysters Australia