Scope and economic analysis of options for a nationally unified breeding program that provides significant economic benefit to the Australian abalone industry

FINAL REPORT

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Scope and economic analysis of options for a nationally unified breeding program that provides significant economic benefit to the Australian abalone industry

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1. Non-technical summary

Well designed selective breeding programs have been the key to the successful development and ongoing viability of major aquaculture industries worldwide. The Abalone Industry has recognised that a nationally unified selective breeding program is needed in Australia and has identified a number of essential requirements for such a program.

There is a need to develop a capacity to achieve maximum rates of genetic gain for the traits selected in as short a time frame as possible. A trait prioritisation exercise was undertaken by a group of farmers, geneticists and industry representatives as a first step for developing breeding objectives for the abalone industry. Traits were ranked on the basis of likely economic impact, potential for genetic improvement, practicality of measurement and selection, demonstrability and amount of research needed. Growth rate emerged as a major trait of importance with behaviour in slab tanks and stress related traits (temperature tolerance, disease resistance, stress with live export and general survival) next in priority. Alternative breeding program designs were evaluated using a computer simulation model. The model used was originally developed to predict the genetic response and consequent economic impact of the application of new technologies with Atlantic salmon selective breeding and was adapted for the abalone situation. Costs associated with selective breeding (lease of facility, feed, power, labour etc.), industry parameters (tonnage, price per kilo etc) and genetic parameters (heritability, trait means, variance and correlations) were estimated by industry representatives and local geneticists. The model was used to predict the optimal selective breeding program design with respect to number of families, presence/absence of overlapping year classes, uptake by growers, selection criteria, selection percentile, larval pricing and investment scenarios. The model showed that selective breeding programs, of a scale which produce 100 or more blacklip and 100 or more greenlip abalone families each generation, would result in strong genetic improvement and have a highly beneficial impact on the efficiency and competitiveness of the Australian abalone industry. If growth rate was the main trait of focus, the model predicted that initially around 10% improvement would be achieved with each generation of selective breeding and after 10 generations the benefit-cost ratio for the industry would be around 200:1, total added benefit per kg of abalone produced would be $18 and nominal economic effect on operating income would be over $60 million per annum (assuming 95% adoption and industry production grows by 100 tonne per year to 3,800 tonnes over the 10 generations).

There is a need to develop a capacity for all abalone breeding initiatives to work collaboratively and value add to each other. Value adding can best occur through collaborative research projects which are prioritised and funded to mitigate risks and address key constraints to selective breeding. Strengths, weaknesses, opportunities and threats were analysed for abalone selective breeding entities and risks associated with selective breeding were ranked on the basis of probability and cost. Research needed to address these risks, constraints and opportunities were then summarised and prioritised on the basis of benefit to selective breeding, likelihood of success and urgency. Control of spawning and mating is a key area requiring research. If spawning could be accurately timed, or if stripping, activation/priming of gametes and/or cryopreservation were achievable, then we could pair mate animals in the most optimal way, of achieving a strong genetic response, while limiting inbreeding and raising economic benefits. A well designed relational database is also a key requirement. Selective breeding entities need to cooperate by undertaking collaborative research, implementing common protocols to allow for data sharing and sharing of genetic material where possible. A common relational database would provide the basis for future unification and collaboration between abalone programs and across aquaculture species.

There is a need for capacity to implement biosecurity measures that will meet state agencies' legislative requirements for translocation and result in sustainability of the program. Translocation and biosecurity protocols and guidelines of relevance to selective breeding programs were highlighted. Necessary considerations (facilities and location, founding stock and quarantine protocols, code of practice for biosecurity control measures and translocation protocols) are outlined.

There is a need for capacity to supply all industry members with selectively bred stock. The industry identified the need for a new selective breeding entity for mainland Australia. Under the current circumstances, the addition of this entity would provide the best means for the majority of the industry to benefit from genetic improvement. There would be advantages if this new selective breeding entity was separated both physically and commercially from existing farms. One of the main reasons for this separation is so that commercial production imperatives do not override selective breeding imperatives.

There is a need for selective breeding initiatives that are commercially, financially and practically feasible in the short (5 years) and long term (10-20 years), with significant economic benefit to the industry. A commercialisation strategy and draft business concept was developed for a proposed stand-alone abalone selective breeding entity (a Pty Ltd company). A stand-alone company would have strong incentives to improve its performance (ie. to achieve a strong genetic response and expand its market base) and thereby benefit major shareholders. Farmers would have strong incentives to invest in the company. The investment cost to farms would depend on the total level of industry participation. By investing the farmers would be given entitlements to larvae and discounts from the company. The discounts will advantage investing farms by effectively reducing the net outlay by these farms on genetically improved larvae. By year 4 the net cash outlay per year on improved larvae would be less than the operating costs incurred by any single farm running a smaller scale selective breeding program (assuming investment by 1/3 of the Australian abalone industry). There would also be substantial benefits for farmers growing the genetically improved stock (ie. faster growth rate, improved feed conversion ration etc). For a 100 tonne farm, investment is expected to yield around $1.4 million in total added production value by year 9. Benefits to farms investing and purchasing selectively bred stock steadily increases with each new generation of selected stock. Annual returns of over $1 million per annum would be expected for a 100 tonne farm by year 19 (excluding offset of expenses from government grants, and excluding growth in revenue due to additional industry uptake). The returns predicted far outweigh those that might be achieved by individual farms running their own selective breeding program in isolation. The commercialisation strategy developed for the new selective breeding entity could be adopted by existing initiatives to help improve their short- and long-term commercial feasibility.

In summary, this scoping study has provided the blueprints for a nationally unified breeding program where genetic gains and economic benefits from selective breeding are maximised, existing and new initiatives are collaborative, research constraints are identified and efficiently addressed on a national basis, and the needs of the industry for strong genetic gain, capacity to service all of industry, commercial and practical feasibility and biosecurity are met.

2. Acknowledgements

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3. Background

The establishment of well designed selective breeding programs has proven a key to the successful development and ongoing viability of major aquaculture industries worldwide. Major world aquaculture species, (eg. Atlantic salmon, rainbow trout, carp, Mediterranean sea bass, white shrimp, catfish, tilapia and oysters) are typically serviced by two or three “centralised” selective breeding programs. In the report below the term “centralised” will be used to mean a selective breeding program that acts in a coordinated way (ie. as one program with a pool, or nucleus, of breeding animals), uses one separate facility (centralised breeding facility) and operates as a separate business entity (stand-alone selective breeding entity). The first such major breeding program was established for Atlantic salmon in Norway by Nofima (formerly Akvaforsk), and the impact of this program has been well documented. Almost the entire production of salmon in Norway, and much of the production in Chile, is from fish derived from this program (eg. sold by Aquagen). Thodesen et al. (1999) compared the performance of unselected animals to selectively bred Atlantic salmon grown under the same conditions after 5 generations of selection on growth rate. The growth rate of the selectively bred fish was more than doubled (+113%), feed consumption increased by less than 50%, protein retention was 9% improved, energy retention was 14% improved and the feed conversion ratio (feed to gain) was 20% improved. After 7 generations this improvement in feed conversion ratio alone resulted in a saving of $300 million in feed costs each year to the US$1-2 billion export industry in Norway.

Typically, in a well designed program, a genetic change of 10-15% per generation can be achieved for a trait like growth rate, and the selective breeding program can yield a benefit-cost ratio of around 15:1 per generation of selection (Gjedrem, 2000) .

The Australian abalone industry gained valuable experience when it embarked on its first selective breeding program several years ago. Through the program, basic methodology for the production of selectively bred abalone was established and the first generation of stock selected for improved growth rate was successfully created. The beneficial impact from selective breeding was well demonstrated to those farms intimately involved in running the program and valuable lessons were learnt about the costs and risks associated with selective breeding. One of the main participants (Mark Gervis, Southern Ocean Mariculture) has summarised the problems of the 1st selective breeding program as being

- a lack of commitment by farms, time taken for committed farms to get a reasonable number of families produced per year,
- individual farm agendas on what they want to produce (from where),
- need to replicate biosecurity on each farm
- high capital cost and
- high operating cost per family to run an effective program.

According to the participants in the first selective breeding program, these problems arose due to

- a poor understanding of the benefits and degree of investment required (including lost production opportunity costs with the generation and maintenance of families for selective breeding),
- commercial production pressures always coming before family production,

- long term nature of commitment not fully appreciated,
- lack of commercial confidence in sending families to receiving farms and
- disease transfer from wild and consequent loss of selected animals.

From this earlier experience there is a strong argument that in re-establishing a program for genetic improvement that will provide significant economic benefit to the Australian abalone industry, we need to establish a ”nationally unified selective breeding program” that spreads the benefits to the majority of the industry.

There are some key isues that are faced by most selective breeding initiatives. All such initiatives need to make strong genetic improvement, need to limit inbreeding, need to create large benefits for stakeholders and need to be commercially viable entities (the latter to ensure continuation of the program and to ensure that benefits continue to accumulate and are passed on to stakeholders in the future). Unification of selective breeding initiatives through common design and through common research projects provides the best means of addressing these needs. Therefore, in this report we model a generic abalone selective breeding program in order to determine how genetic response, economic benefits and commercial viability should be optimised. Existing programs can use this information to modify their practices, new programs which aim to service the rest of the Australian industry can use the information provided to begin selective breeding in an optimal way.

Abalone selective breeding programs have recently been initiated by a Tasmanian consortium and by Great Southern Waters in Victoria. The motivation for this scoping project has been to seek ways to unify all abalone selective breeding initiatives for the benefit of the entire industry. In providing a unified, centrally coordinated selective breeding program for the abalone industry there should be advantages in that:

- the benefit would be realised by more farms,
- costs per farm would be reduced,
- commercial production imperatives will not override selective breeding imperatives,
- larger numbers of families could be produced,
- faster rates of improvement could be achieved,
- a broader genetic base could be established in the beginning,
- inbreeding depression of fitness would be limited,
- a strict timetable and plan for selection and production of families could be followed,
- biosecurity could be both addressed on-site and by receiving farms and
- potential for year round spawning could be realised.

The key issues to address in establishing and running any selective breeding program are as follows:

1. Detailed methodology for the program (practicality and costs)
2. Breeding objectives and traits
3. Risks and risk management
4. Key researchable constraints
5. Cost-benefits of alternative models for running the program

6. Commercialisation of the program (investment, pricing, returns to shareholders)
7. Where and how (facilities- public, private, leased or owned)?

All of these issues can be modelled and the pathway which provides a balance between genetic response, avoidance of inbreeding, avoidance of loss of genetic variation, high economic benefit to industry, and cash flows/returns to the selective breeding company can be predicted. This report is largely the outcome of such modelling for the industry. The bioeconomic simulation model we use was developed by the principle investigator through project work in Norway with Nofima on Atlantic salmon (Akvaforsk-Fiskeriforskning AS) (Robinson, Hayes, 2008) and adapted by the principle investigator to the situation for the abalone industry in Australia.

4. Need

Determine how to best meet AAGA's objectives for the supply of selectively bred stock to the industry. These objectives are:

- Capacity to achieve maximum rate of genetic gain for the traits selected
- Minimum time until the supply of improved stock can meet the demand by the industry
- Capacity to service all industry members (including land-based farms without hatcheries and at-sea farms)
- Commercial, financial and practical feasibility in the short (5years) and long term (10-20 years), with significant economic benefit to the industry
- Capacity to implement biosecurity measures that will meet state agencies' legislative requirements for translocation and result in sustainability of the program (ie. not affected by disease issues)
- Capacity for all abalone breeding initiatives to work collaboratively and value-add to each other

5. Objectives

1. To model the Tasmanian/GSW program(s) and alternative mainland strategies, and determine the optimal strategy for a unified, centrally coordinated program. The aim was not to compare breeding programs against each other, but rather to provide an economic model of each, recognising infrastructure, running costs, capacity to produce families, commercial viability, co-investment with partners across sectors, etc, that will deliver a breeding strategy (breeding design and objectives) for each initiative to allow them to maximise their genetic gains and economic benefits (benefit to cost ratio).

2. To identify the areas of collaboration for adding value to each program and the standardisation of procedures needed to ensure collaboration is achievable.

3. To identify key researchable constraints to the implementation of the breeding programs, prioritise the research objectives and identify funding options.

4. The cooperative breeding program that develops should aim to achieve the objectives of AAGA, as listed in the Needs section.

6. Methods/Results/Discussion

6.1 Initial trait prioritisation

Rationale

In meeting the first objective to model selective breeding programs for abalone and to "determine an optimal strategy for a unified centrally coordinated program", and in meeting objective three "to identify key researchable constraints to the implementation" of selective breeding programs, it was necessary to first determine which traits should be the focus of abalone selective breeding programs.

In deciding on traits that we should focus on in a breeding program, it is important to consider economic impact, genetic parameters and implications on the potential for genetic improvement (trait of focus and correlated traits), the practicality of measurement and selection, demonstrability (affecting uptake by growers) and the amount of research needed (could the trait be selected now). Most selective breeding programs start very simply (focussing on one or two important traits). Additional traits can be added later as the program develops and some traits, such as meat quality traits, can be monitored to check that no deleterious correlated side effects are encountered.

As a group exercise, industry participants and geneticists (listed in Appendix 3) were asked to identify the features of abalone that they would like to see improved with selective breeding. We then performed a consensus evaluation of whether each feature was good/OK/bad or high/medium/low with respect to likely economic importance, practicality, demonstrability, expense of measurement, heritability, correlated effects on other traits, state of knowledge and research needed to be able to select for the feature. This exercise was carried out to give broad starting options for our modelling of the program.

The results from the trait prioritisation exercise in the workshop are shown in Table 1. Growth rate emerged as the major trait that breeding programs should focus attention on. Faster growth rate to target size it was thought would have a big economic effect and would be practical and simple to select for. Improvement in this trait could be easily demonstrated on farm and would be inexpensive to measure. The trait is likely to have a high heritability and favourable correlations are likely with feed conversion efficiency (eg. Atlantic salmon, Thodesen et al. 1999). The science of genetic improvement of this trait is relatively well known and little research would be needed.

The next two traits worthy of attention were related to behaviour (particularly the elimination of undesirable clumping behaviour in blacklip abalone) and the general stress traits (temperature tolerance, disease resistance, stress with live export and general survival). It was thought that if the behavioural problem could be overcome in blacklip abalone, a large number of farms with a slab tank design might change to farming either blacklip or hybrid abalone. Anecdotal evidence from the last breeding program suggests there was considerable variation between families for clumping behaviour of blacklip abalone and that maybe this trait is quickly influenced by domestication. A possibility is to put some emphasis on the behaviour of blacklip abalone (less emphasis in the greenlip line) for a few early generations in the program until this problem is resolved.

Of the stress traits, temperature tolerance is probably the most practical to work with, however all these traits require at least some research (disease resistance or tolerance requires substantial research), all are indirect (in that survivors will either be affected or infected during the testing process and are therefore likely to be unsuitable as breeding candidates) and most are likely to have a low heritability and therefore would be relatively slow to improve.

Sexual maturity (time to maturation), general survival and meat quality are traits that we would need to keep an eye on as the breeding program progresses. There was a consensus that time to maturation should not be shortened by selective breeding. This is because gonad maturation and spawning has noticeable undesirable effects on the condition of abalone. However to increase the rate of genetic improvement for the breeding program it is desirable to shorten the generation interval for these species. Therefore, we need to be able to artificially induce early maturation among animals in the breeding program. General survival is a complex trait that would be influenced by different factors in different years and at different locations. Therefore it is likely to be difficult to improve (there is low heritability for this trait in other species) unless it is highly correlated with another important trait under selection.

Colour (greens made greener, blacks made whiter, blacker and/or striped) is likely to have a simple mode of inheritance involving few genes. Differentiation according to colour might be best achieved at the "multiplier level" of the breeding program. Multiplication in this case would simply be through the sale of surplus larvae, resulting from the production of families for selective breeding (ie. the dissemination of genetic gains would not be delayed). We could sell surplus larvae that are likely to inherit the customers desired colour patterning. In this way, we would <u>not</u> select for particular colour variants within the breeding program, but would have the opportunity of supplying any variant or combination of variants that is required to the producers in any given year. But some research is needed to determine the mode of inheritance of colour traits.

Table 1. Results from the trait prioritisation exercise

Feature	**Growth rate (GR)**		**Sexual maturation (SM)**	**Colour**	**Behaviour**	**Temperature tolerance (TT)**	**Vibrio/stress (DR)**	**Stress with live export (SLE)**	**General survival**
Trait	**Meat yield (size/shape) Market pays for $total weight with shell**	**Winter growth rate. Ie. research needed to see if emphasis needed**	**Late maturation in terms of gonad size and spawning ability**	**Greens greener, blacks whiter, striped blacks, black blacker**	**Blacks clumping (greens also). Movement, light sensitivity, mantle**	**Summer tolerance decreases with age. Test sticking to plate. Blacks more of a prob, bay blacks good.**		**Greens**	**Problem in that different factors will have effect in each year and on each farm**
Economic potential	**√√√**	**√√√**	**√√√**	**√√**	**√√√**	**√√√**	**√√√**	**√√**	**√√√**
Practicality	**√√√**	**√√**	**√√√**	**√√√**	**√√√**	**√√**	**√**	**√√**	**√√√**
Demonstrability	**√√√**	**√√**	**√√**	**√√√**	**√√√**	**√√**	**√√**	**√√**	**√√**
Expense (measurement)	**√√√**	**√√**	**√√√**	**√√√**	**√√√**	**√√**	**√**	**√√**	**√√?**
Likely heritability	**√√√**	**√√**	**√√**	**√√√**	**√√?**	**√√?**	**√**	**√√?**	**√**
Correlations	FCR **√√√** DR **???** MQ **√?** SM **√**	GR **√√√** FCR**√√√**	GR **√** MQ **√√√**		GR **√√√**	GR **√√√???** SM **√√√???** DR **√√√???** SLE **√√√???**	GR **√√√???** SM **√√√???** TT **√√√???**	TT **√√√???** GR **√√√???** DR **√√√???**	GR **√√√???** DR **√√√** TT **√√√**
Science on trait	**√√**	**√**	**√**	**√√√**	**√√**	**√**	**√**	**√**	**√**
Research needed	**√√**	**√**	**√**	**√√**	**√√** nice PhD	**√√**	**√**	**√√**	**√√**
Selection may not be necessary, but changes should be monitored.			**√√√**	**√√√**	**√√**				

√√√ high/good; √√ medium/OK; √ low/bad

Results from the trait prioritisation exercise, continued

Feature	**Meat quality (MQ)**
Trait	**Unsure. Would need extensive market analysis. Taste, juiciness, texture??**
Economic vibe	**√√√**
Practicality	**√**
Demonstrability	**√**
Expense (measurement)	**√**
Likely heritability	**√**
Correlations	GR **√** SM **√√√**
Science on trait	**√√**
Research needed	**√√**
Selection may not be necessary, but changes should be monitored.	**√√√**

√√√ high/good; √√ medium/OK; √ low/bad

6.2 Strengths, weaknesses, opportunities, threats and risk analysis

Rationale

In meeting objective 3 and identifying "key researchable constraints to the implementation of breeding programs" it is important to understand what the strengths, weaknesses, opportunities and threats associated with selective breeding abalone might be, and what risks need to be addressed.

Table 2. Strengths weaknesses, opportunities and threats identified for selective breeding entities. Some points in the SWOT analysis depend on the type of entity under consideration. ** indicates where these points relate specifically to a centralised selective breeding entity supplying a large proportion of the industry.

Strengths	Weaknesses
Industry support & knowledge Services most of industry** Large economic benefits for growers** Stimulus for expansion Stimulus for new entrants** Advantage over competitors Small scale (inexpensive) compared to farm or livestock breeding programs Multiplier an integral part of program and no additional investment needed to "gear-up" to increase supply Closed to further entry of new animals leading to reduced risk of disease Helps meet increased demand for seafood and reduced volume of supply from wild fishery Farms save $$ and risk as no need to spawn and mate** Farms running their own on-farm selective breeding programs save resources (potentially hundreds of thousands of dollars in lost opportunity costs) and benefit from a better (more improved) product** Future product allows farms to produce more from use of same resources Genetic improvement and benefits compound with each generation of selection Flexibility to supply blacklip, greenlip or hybrids in volumes desired by market each year	Size and limits (regulations for land-based farms) on growth of industry Price farmers are willing to pay for stock Division in industry (Tas/Mainland, on-farm breeding/centralised breeding) Industry consists of a small number of farms and the costs of producing and supplying genetically improved seed are essentially the same whether the industry is small or large. Because of this the total benefits-costs, and profitability of the selective breeding entity, are less than for larger aquaculture industries. Above points limit possible revenue stream and reduces attractiveness to investors Succession planning (ie. three staff to operate)

Opportunities	Threats
Merge with other selective breeding companies (national or international) Share genetic expertise with other selective breeding companies (eg. national organisation) New or niche markets (well behaved blacklips, colour/patterning preferences) Year round or “pre- spawning season” supply	High AUS$ continues or value of abalone product slumps Primary industries rules prevent translocation of improved seed to sea based facilities or restrict sea based farms to locally sourced varieties Translocation between mainland states is restricted by primary industries** Bad press stemming from competition (eg. abalone divers association) Contamination from pollution, algal blooms or disease Loss of key hatchery management staff or quantitative geneticists Global warming Competitors arise

6.3 Strengths, weaknesses, opportunities, threats and risk analysis

Rationale

In meeting objective 3 and identifying “key researchable constraints to the implementation of breeding programs” it is important to understand what the strengths, weaknesses, opportunities and threats associated with selective breeding abalone might be, and what risks need to be addressed.

Table 2 is self explanatory. There are a number of strengths in support of the centralised program in particular, (eg. good opportunities for growth and expansion of such a program) and some weaknesses and threats that need to be taken into consideration and addressed where possible for all selective breeding entities. Threats and weaknesses have been included in a risk analysis (Table 3) and suggestions for risk management have been made. Some of the key constraints for the breeding program might be overcome through research (ie development of new technologies and methods) and an attempt has been made by the research provider participants in the project (with input from industry participants Nick Savva and Mark Gervis) to prioritise the research needed (Table 4).

Table 3. Risk analysis for selective breeding entities. Ratings for A and B. 3=high probability/cost, 2=medium probability/cost, 1=low probability/cost

Threats/risk	Prob of event (A)	Amount it would cost to set things right if happened (B)	Estimate of value for risk (A*B)	Managing risk
High AUS$ continues or value of abalone product slumps	2	3	6	Accept risk. As improvement is made to the stock that is grown the industry will become more resilient to this risk.
Primary industries rules prevent translocation of improved seed to sea based facilities or restrict sea based farms to locally sourced varieties	2	3	6	Produce infertile stock for growout. Research needed into genetic and other methods. Demonstrate strict biosecurity and quarantine measures.
Contamination from pollution, algal blooms or disease	2	3	6	Contingency for total recirculation. Stock tested on farm can be retrieved in emergency.
Bad press stemming from competition (eg. abalone divers association)	2	2	4	Produce infertile stock for growout. Research needed into genetic and other methods. Demonstrate strict biosecurity and quarantine measures.
Competitors arise (in Aus)	1	3	3	Stay ahead (optimised methods, research, protection)
Survival of larvae is poor after several hours of transport	1	3	3	Trial time and conditions, larval stage, vehicle (temp vibrn etc) to optimise
Translocation between mainland states is restricted by primary industries	1	3	3	Demonstrate strict biosecurity and quarantine measures.
Loss of key hatchery management staff or quantitative geneticists	1	2	2	Accept low risk. Provide good working environment (peers, location etc) and national support network for aquaculture breeding programs
Global warming	2	1	2	Breed for high temperature tolerance

6.4 Biosecurity, quarantine and translocation risk management

<u>Rationale</u>

In order to meet objective 4 and to "achieve the objectives of AAGA", selective breeding programs need to have a "capacity to implement biosecurity measures that will meet state agencies' legislative requirements".

It will be important for selective breeding programs to establish procedures and facilities that provide for a biosecure environment. It is also important to put in place procedures so that genetically improved stock are "backed up" at other locations in case a disease outbreak occured in the nucleus. Each state in Australia has its own disease management and translocation policies and codes of practice. The protocols and facilities developed by the breeding entities should go beyond the minimal requirements that are stated in these government policies. It is important that the breeding entities do so in order that:

- The industry can have a high level of confidence that serious diseases will not be transmitted from the nucleus of animals within the facility to their farms
- Abalone divers and groups concerned with the wild abalone fishery can be confident that serious diseases will not be transmitted from the breeding nucleus to the fishery
- Government departments of Primary Industries can have a high level of confidence in the selective breeding program and industry. The biosecurity measures and track record of the breeding program and industry will no doubt have some influence on Commonwealth and State government policy decisions and on approvals given by the Chief Veterinary Officers.
- The breeding nucleus can act as reliable source of back-up stock if disease affects the farms or the fishery.

Relevant translocation and biosecurity protocols and guidelines can be found at:

State Government of Victoria, Department of Primary Industries
http://www.dpi.vic.gov.au/dpi/nrenfaq.nsf/linkview/d80f34e347681409ca25717f00198944f5f3c3da915afbe4ca256c6f0016ca60

State Government of Western Australia, Fisheries

http://www.fish.wa.gov.au/docs/mp/mp133/fmp133.pdf

http://www.fish.wa.gov.au/docs/pub/LegislationHow/gateway.php?0006

State Government of South Australia

http://www.legislation.sa.gov.au/LZ/C/POL/Aquaculture%20Aquatic%20Organism%20Translocation%20Policy.aspx

State Government of Tasmania

http://www.dpiw.tas.gov.au/inter.nsf/WebPages/SCAN-75F423?open

http://www.dpiw.tas.gov.au/inter.nsf/WebPages/LBUN-6R2826?open

Facility and location. Preference should be given to facilities that would enable some degree of recirculation, filtering and treatment of incoming and outgoing water, temperature control and distance from existing natural populations of abalone.

Setting up the breeding nucleus in year 1-importation of founding stock and quarantine protocols. Ideally it would be best to restrict the importation of animals into the breeding nucleus to year 1. If the population is not closed in year 1, and a disease is introduced down the track with the importation of further stock, there is a risk of wasting years of time and money. The screening of these founding animals for diseases will be of major importance to the selective breeding program. If it is possible to do so, and if a reasonable level of biodiversity can be represented, all founding animals for the breeding nucleus should be sourced from existing farms. Only stock that has had its health status certified will be accepted into the selective breeding program. If possible, only animals that have been handled and closely monitored, with a clean bill of health for over one year on-farm, could be used as founding animals for the breeding program, so long as an adequate representation of founding biodiversity can be achieved and inbreeding can be managed. All animals that are to be considered as founding animals will be quarantined monitored and tested for several months before being introduced to the main pool of breeding animals. As it is possible that some animals may be “carriers” of particular harmful diseases (ie. tolerant or resistant and showing no signs of the disease) and that others may be “naive” (ie. not previously exposed to such diseases), the quarantine procedure will involve some co-habitation of animals from different locations. It may also be necessary to apply mild stresses to the animals under quarantine (eg. raised water temperatures) to try to induce disease symptoms.

Code of practice for aquaculture biosecurity control measures
Biosecurity would be achieved by applying a number of tools and protocols designed to prevent, control and eradicate infectious diseases. A biosecurity code of practice has been established for abalone farms (Gavine, et al., 2007) which focuses on measures to control abalone viral ganglioneuritis. This code of practice, which consists of a series of Standard Operating Protocols (SOPs) should be followed by the selective breeding programs. Gavine et al*.* (2007) identified that major risks of spreading the virus were associated with movement of live abalone, movement of equipment and personnel, water movement and inappropriate disposal of mortalities. A number of other guidelines for maintaining the health and well being of farmed stock exist and should be consulted by the operators of the selective breeding program (eg. Bondad-Reantaso, F., 2005; Elston, Cheney, 2004; Ingram, et al., 2005). Gavine et al. (2007) detail the following areas of importance for biosecurity:

Health management

1. Health surveillance program
2. Identification and reporting
3. Stock management

Quarantine procedures (water, equipment, importation of stock)

Sanitation procedures

1. Routine cleaning of culture units
2. Periodic cleaning of pipe work and wastewater channels
3. Footbaths
4. Disinfection of influent and effluent water

Exclusion of disease agents

1. Entry and movement of personnel, contractors and visitors
2. Movement of equipment

Preventing disease agents from exiting the farm

1. Preventing escapees
2. Disposal of mortalities
3. Effluent treatment
4. Translocation protocols

Abalone translocation protocol

After the selective breeding program is established in year 1, the only movement of abalone involving the breeding facility should be the translocation out of the facility to farms. For this movement State translocation protocols and controls will be closely followed (eg. Anonymous, 2007).

In summary, there are a number of state, commonwealth and ASEAN protocols that have or are being developed and should be followed for the biosecurity, translocation and use of recirculating aquaculture facilities. Selective breeding programs should aim to exceed industry best practice standards, should have a transparent public reporting system and regularly consult with users and government departments and veterinarians so that all the users of the program can be assured of the health of the stock that they are purchasing.

6.5 Key researchable constraints for selective breeding programs

<u>*Rationale*</u>

Prior sections of the report have provided background information that is needed to fulfill objective three which is "to identify key researchable constraints to the implementation of the breeding programs, prioritise the research objectives and identify funding options". The way in which these research needs for selective breeding can be met also relates to objective 2 which is "to identify the areas of collaboration for adding value to each program and the standardisation of procedures needed to ensure collaboration is achievable"

A workshop was held to identify research priorities by scoring research areas on the basis of benefit to the selective breeding program, likelihood of success and urgency. Table 5 gives us an indication of the order for prioritisation purposes. Although there wasn't time in the current project, it would be possible to use the simulation model to predict what the economic benefit (in AUS$) from these research areas might be.

Table 4. Key researchable constraints for selective breeding programs. Ratings for A, B and C. 3=high rapid benefit/likelihood, 2=medium benefit/likelihood, 1=low long-term benefit/likelihood

Constraint/opportunity	Research/development needed	Benefit to SBP if eliminated/ reduced (A)	Likelihood of success (CRC life) (B)	Urgency (C)	Priority (A*B*C)	Notes
1. Control of spawning and mating (early induction, accurate timing, year round, stripping, sperm & egg priming, cryopreservation)	1. Cues in controlled (eg. recirc) environment (+ve & -ve). 2. Basic physiology and possibilities for manipulation 3. Cryopreservation (see below)	3	3	3	27	Critical for selective breeding to improve rate of genetic improvement (shorten generation length and increase selection intensity). Cryopreservation can be achieved, but with variable success (quantity and quality). Some work being done by Xiaoxu and some may begin through collaboration between CSIRO and Cawthron NZ.

2. Organisation of data	Professional relational database	3	3	3	27	Cross-sector tool needed. Key considerations- flexibility, in-built functions and checks, maintenance, comment rich, allowing automated field entry, web-based with varying levels of access (privileges). Nick R. to look into CSIRO system with Peter Kube.
3. Survival of larvae with transport	Trial time and conditions, larval stage etc	3	3	3	27	Xiaoxu has found dry transport (wrapped in mesh from banjo filter) for a few hours leads to no loss of viability. No problems for oysters under dry transport (Nick Savva has noted improved performance with transport). Some small scale trials needed.
4. Animal identification (tagging and DNA testing)	Trial different systems (eg, spring with pit tag).	3	3	3	27	Tag earlier, reduce tag loss, easily identified, reduce recording errors. Combined spring tag with pit tag? Keep check on costs of DNA typing (cross sector project with CRC).
5. Blacklip behaviour	Selection/domestication Physical modification	3	3	2	18	Benefits growth in slab tank system. Research and selection/domestication will occur as part of program anyway.

6. Challenge tests	Disease? Other factors affecting survival? Propogation -virulent Method of infection Dose Which disease?	2	3	2*	12	*CSIRO ARL already investigating potential for resistance to virus. CRC PhD on abalone defence system beginning. QX oysters a good case study. Use these as test cases. Identify and expand research in promising areas. Co-support from fishery sector?
7. Hybridisation	Performance, selection of contributing species, fertility, performance of hybrid*hybrid and hybrid*pure	2	3	2	12	Focus of current CSIRO (GSW) work (ie. does good blacklip * good green give good hybrid). Discuss with Anton K. availability of data and where value might be added.
8. Govt concerns over genetic impact with supply to sea-based farms	A. Sterilisation (ploidy, hybridisation, natural chemical, other)	3	3	1	9	Tactical issue that needs to be addressed (ie would assist with growth of market to sea-based industry or overseas, and with green image of abalone farming). Could be more important if sea-based production increases.
	B. Population genetic model of wild fishery.	3	2	1	6	Model potential for genetic impact and physiological effects. Substance to models.
9. High and low temperature stresses	Heat tolerance	3	3	1	9	Common thread across sectors. Keep a watch on research

	Winter growth	3	3	1	9	activities in other sectors and validate for abalone if potential.
10. Biosecurity	Tests to assess biosecurity threat. Tests for health certification.	3	3	1*	9	*AARL and Vic DPI research already in progress. May need to expand research in some critical areas.
11. Rate of improvement in disease resistance or meat quality	QTL genome scans Integration of MAS. But need challenge tests first.	3	2	1	6	Strategic issues that will become important down the track.

The workshop identified that the two most important areas for research are the control of spawning and mating, development of software tools for common organisation of data, survival of larvae with transport and animal identification.

Three areas of research focus are needed to tackle the problem of control of spawning/mating, 1. Improved understanding of cues for spawning in a controlled (eg. recirc) environment, 2. Basic physiology and possibilities for manipulating reproduction, and 3. Cryopreservation. There is some work already underway on cryopreservation and the control of spawning in abalone (eg. Cawthron). Spawning cues and basic physiology are likely to be fairly particular to abalone, and so a cross-sectorial approach might be not be useful in this instance. The breeding entities might be able to attract commonwealth funding together to tackle this problem.

Trait relational databases are a key requirement for any breeding program. These databases are normally very specific to the species in question and in the past have been built largely from scratch. The sort of database backbone systems used include MySQL and Oracle. User friendly front-ends can be built into such systems. The design, maintenance and upgrading of these relational databases is important and can be expensive and ongoing. Specialist ongoing support is needed to keep the database alive and well. Sharing of a common relational database system by selective breeding programs would provide a solid grounding for future unification and collaboration between the programs. There is a need across the aquaculture industries for such database systems and the abalone industry could benefit from a generic system. Further investigation of such generic systems will most likely occur within the Seafood CRC.

Survival of larvae with transport and animal identification are high priority areas that might also be of cross sector importance. Both problems can likely be resolved by conducting relatively small trials. The selective breeding entities could conduct these trials as part of their normal business practices.

Possible sources of research funding include the Australian Seafood CRC and other sources listed in the attached business proposal for the selective breeding program (Appendix 7). The CRC would give highest funding priority to cross-sectoral issues (eg. points 2 & 9, and parts of points 1,6, 8, 10 & 11). Selective breeding entities would need to apply for commonwealth or state research funding to address other issues identified above. It is intended that all procedures that are developed would be published and standardised or calibrated so that they can be utilised by all abalone selective breeding initiatives in Australia. In this way all breeding programs are facilitated and benefit from the research efforts.

6.6 Why model selective breeding programs using simulation?

<u>*Rationale*</u>
In order to fulfill the first objective of the project and "determine the optimal strategy for a unified, centrally coordinated program" there is a need to develop a generic bioeconomic model for an abalone selective breeding program.

We want to determine

1. Which traits we should focus on and how should we perform the selection of these traits to give the best value to the industry?
2. Cost-benefits of alternative ways of running breeding programs (design of the selective breeding programs)?
3. Profitability of programs? (ie. the output from the model is essential for the development of a business plan).
4. The most effective use of new technologies (eg. Marker Assisted Selection)?

All of these calculations are complex, repetitive and time consuming. Chance plays a large role in affecting the outcome of these calculations. By simulating a number of breeding programs over time we can make predictions about how traits will respond to selective breeding (average genetic response and variation in response) and how the economics of the industry will be impacted by these changes.

6.7 Parameters used as input into the simulation model

<u>*Rationale*</u>
The model that is used to achieve the first objective to "determine the optimal strategy for a unified, centrally coordinated program" needs to be populated with parameters that are specific to the abalone industry in Australia (costs, size of industry, value of product etc). In developing an "optimal strategy for a unified, centrally coordinated program" it is necessary to vary some parameters in the model and see what effect they have on genetic response, economic benefit and cost of the program.

Appendix 4 details all of the parameters that were used as input into the simulation model for abalone. All parameters were obtained through one-on-one discussions with farmers and geneticists and through a workshop held with industry participants and geneticists (Appendix 3). The following factors (highlighted in red in Appendix 4) were varied and tested by simulation:

1. *Number of families*- Three different scales for the breeding program were compared. We ran the simulations using 33, 100 and 150 families. We only considered the production of full-sibling families for the simulation. We assumed that around 100 offspring from each family would be needed as mature breeding candidates.

2. *Broad design with and without overlapping year classes*- We chose 33 families as the lowest number to test as this could also be used to compare selective breeding programs that have three overlapping year classes (at 33 families per year class) to those with non-overlapping year classes (with 100 families per generation). Similar average yearly running costs would be encountered by these two types of selective breeding programs.

We also need to consider the avoidance of inbreeding depression, particularly in the program with overlapping year classes, as the number of families is low. Matings between the three year classes would need to be carried out periodically in order to avoid inbreeding depression of fitness. This would mean that all year classes would need be grown and maintained for additional years, periodically, so that all year classes could be spawned (assuming that cryopreservation was not possible). This would also reduce the rate of genetic gain achievable over the years. The avoidance of inbreeding depression with smaller family numbers will inevitably result in lower selection intensities, and less genetic response, than for selective breeding programs using larger family numbers (see how the selection intensity was varied in point 5 below).

3. *Uptake of product from selective breeding program by growers*- Two different patterns of uptake were compared when modelling the industry wide benefit-cost ratios. The first assumed that 75% of the industry in Australia (most of the mainland growers) utilised the seed produced by the selective breeding program from the programs first year of operation and that growth of adoption was steady after that (peaking at 95% after 8 generations, Figure 1 – uptake profile 1). The next assumed that 50% of growers utilised the stock produced by the selective breeding program in the programs first years and that the proportion of industry using the stock rapidly grew over the next two generations to 95% (Figure 1 – uptake profile 2). Both uptake profiles assumed a total slaughter weight for the industry over years of selective breeding are shown in Figure 3. For the business proposal in Appendix 7 a more conservative uptake was assumed (a steady 33% of the industry over all the years, Figure 3 of Appendix 7).

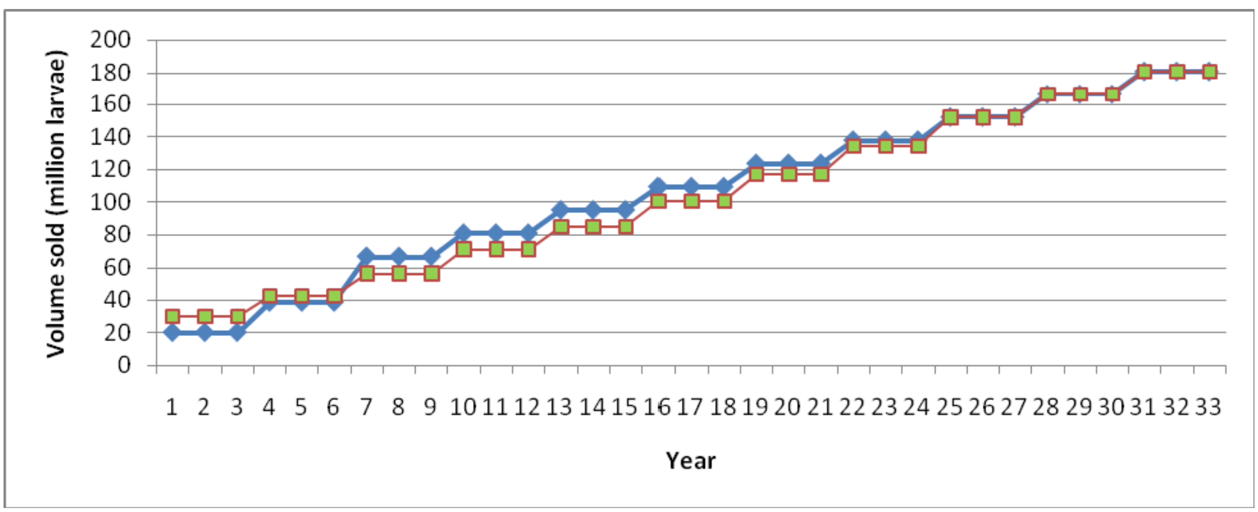


Figure 1. Assumed patterns of uptake (millions of larvae sold over years) for the selective breeding program. Green squares, uptake profile 1: blue diamonds, uptake profile 2.

4. *Selection criteria including the use of MAS technology for selection of difficult traits*- We focussed on two quite different traits, one that could be simply and directly measured and selected (growth rate) and a stress trait which was not so easily selected (disease resistance). All of the stress traits are likely to have low heritability relative to growth rate. Also, it is likely that when the animal is tested for its response to one of these stresses, that it will either be

weakened, infected or killed in the process. Although improvement in each of the stress traits will have different economic benefits and costs, we chose to focus our simulation on disease resistance in this instance as I already have a working model for this trait. The selection criteria applied to these different traits (direct, family breeding values and indirect) are described in detail below.

5. *Selection intensity*- In order to limit inbreeding, it would not be possible to have as high a selection intensity for the selective breeding program generating 33 families each generation as for the programs with 100 or 150 families each generation. Therefore we assumed the selection percentiles given in Table 5.

Table 5. Assumed selection percentiles for the different selective breeding programs.

	Number of families X family size					
	33 * 100		**100 * 100**		**150 * 100**	
Selection percentile assumed when selecting best individuals across families (IND) or when selecting mate pairs from the best families (EBV)	20% IND	25% EBV	10% IND	15% EBV	5% IND	10% EBV

6. *Pricing and investment scenarios*- Appendix 5 shows the scenarios for pricing and investment that were tested. Later in the report (Section 6.12) we just focus on the most promising pricing/commercialisation strategy and the results predicted with its implementation. In agreement with AAGA, a business proposal has been developed on the basis of this strategy (Appendix 7).

Comparison of different traits and selection criteria. We compared 4 different selection criteria for each of the different scales of breeding program. These criteria are presented in Figure 2. Criteria 1-3 focussed on resistance/tolerance to a disease such as *Vibrio sp*. while criteria 4 focussed on growth rate. For *Vibrio sp*. resistance/tolerance we:

CRIT1 - selected families based on estimated family breeding values for disease resistance (response to disease challenge ie. trait 1)

CRIT2- tested all animals and predicted phenotype using a molecular genetic test (eg. gene expression profiling or marker assisted selection) and selected those animals who ranked the best for this trait (trait 2).

CRIT3 – used a combination of CRIT1 and CRIT2 by selecting families based on estimated family breeding values for trait 1 and selecting within these families based on trait 2.

For growth rate we:

CRIT4 - selected males and females who had the highest harvest weight in a fixed growing period (trait 3).

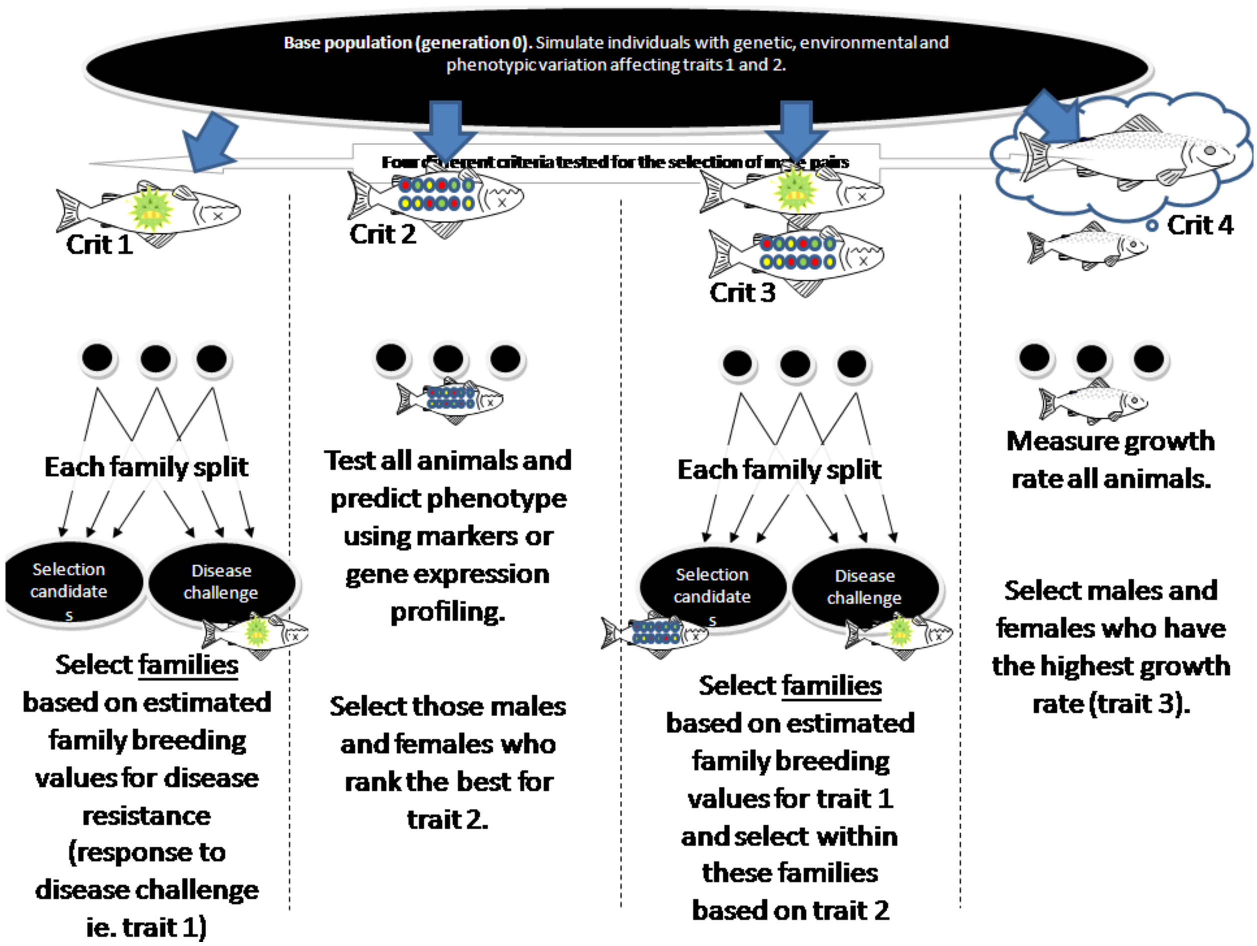


Figure 2. Selection criteria compared for the three different scales of selective breeding program. These are similar selection criteria to those used in modelling selective breeding programs for Atlantic salmon (Robinson and Hayes, 2008)

Single trait at a time only. Only the effects of selection on a single trait at a time were studied. Only well known correlated effects in other fish species (growth rate with feed conversion ratio) were considered.

Assumed projected production volumes. Projections of production volumes are shown in Figure 3 (source Shane Mclinden).

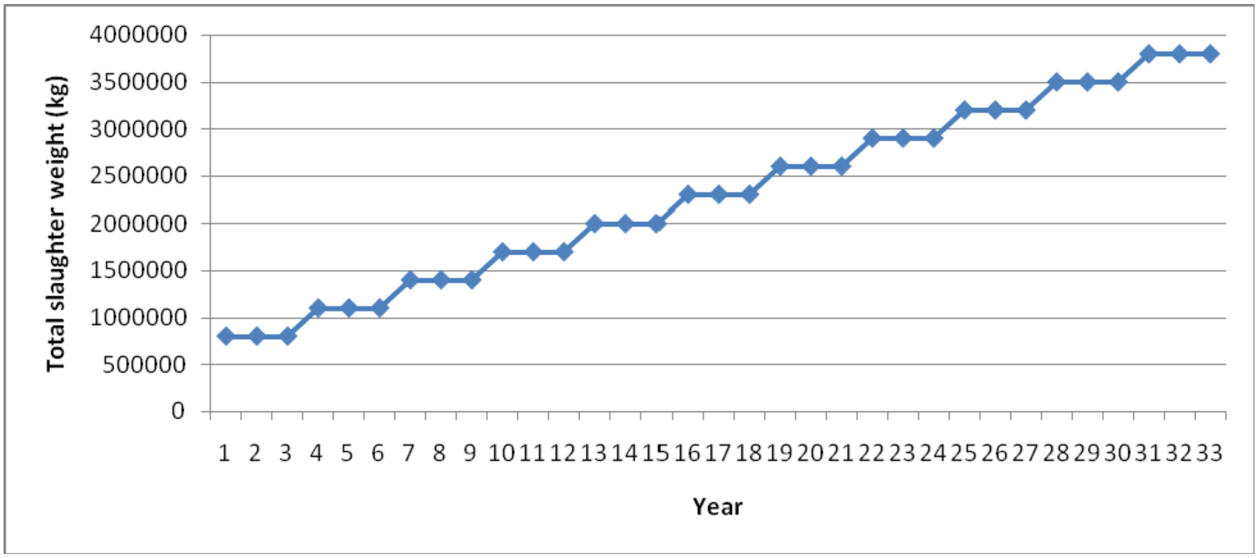


Figure 3. Total slaughter weight of Australian abalone industry (kg) assumed under all scenarios (average industry growth of 100 tonne/year).

6.8 Outline of the simulation model

<u>*Rationale*</u>

This section describes the model that was adapted and used to fulfill objective one "To model the Tasmanian/GSW program(s) and alternative mainland strategies, and determine the optimal strategy for a unified, centrally coordinated program. The aim was not to compare breeding programs against each other, but rather to provide an economic model of each, recognising infrastructure, running costs, capacity to produce families, commercial viability, co-investment with partners across sectors, etc, that will deliver a breeding strategy (breeding design and objectives) for each initiative to allow them to maximise their genetic gains and economic benefits (benefit to cost ratio)".

A general overview of the simulation model is shown in Figure 4 (a more detailed explanation of the model can be found in Robinson and Hayes (2008), and additions made to the model to accommodate the situation for abalone will be the subject of a future paper). We simulated families of animals, selected in different ways for different traits with different genetic parameters. The average genetic change in the population of animals is the genetic response. The genetic response leads to some economic benefits and also comes at a cost (eg. more tanks, labour, feed to maintain selection candidates etc). All of the assumptions shown in Appendix 4 can be varied in the model. As better information comes to hand we can re-run the simulations and make new predictions.

The phenotype of an animal (ie. its measured growth rate or tolerance to disease) is determined by the animals genotype (genetic makeup) and environmental effects (eg. quantity of feed, water temperatures etc.). When we run a selective breeding program we are often measuring and selecting animals based on their phenotype (unless we estimate family breeding values or use gene markers in which case we use an estimate of the animal's genotype). The simulation model picks animals depending on the selection criteria we apply, mates pairs of selected animals together, determines the genetic makeup of sons and daughters based on the inheritance of additive genetic variance from their parents and randomly generates environmental effects every generation.

The economic model is based on the principle of alternative costs. Eg. When considering disease tolerance or resistance we consider:

- How many more abalone would we expect to survive disease outbreaks across the industry or how much more tolerant and productive would the abalone be? What is the opportunity cost (increased value of production less increased cost of feed)?
- What are the accumulated savings from the reduction in compensation abalone?
- What are the economic benefits from savings in labour costs resulting from reduced removal and disposal of dead abalone?
- What are the costs of applying different selective breeding criteria?

When considering growth rate (harvest weight after a fixed 3 year farming period) we consider:

- What is the opportunity cost (increased value of production less increased cost of feed accounting for correlated improvement in feed conversion ratio)?
- What are the economic benefits from savings in labour costs per kilo of production?
- What are the costs of applying selective breeding criteria?

The economic model calculates:

- Total added benefit per kg of abalone produced (benefits divided by the slaughter weight of selectively bred abalone that were grown out by the industry)
- Benefit–cost ratio (benefits divided by costs)
- Nominal economic effect on operating income (benefits – costs)
- Net present value (present value of net cash flows)
  - Internal rate of return (indicator of efficiency of investment)

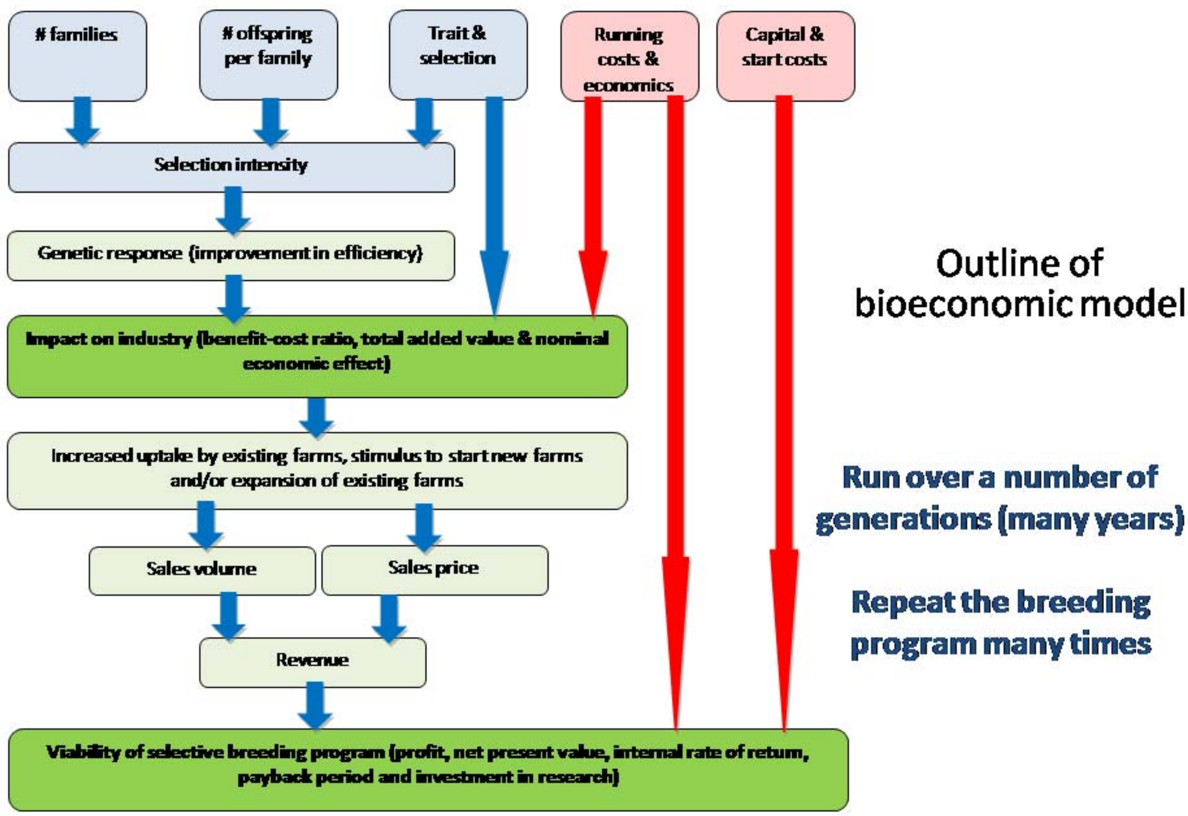


Figure 4. Broad outline of the bioeconomic model used to predict genetic response and economic outcomes from running the selective breeding program.

6.9 Genetic response predicted

<u>*Rationale*</u>

This section relates to objective one which was "To model the Tasmanian/GSW program(s) and alternative mainland strategies, and determine the optimal strategy for a unified, centrally coordinated program. The aim was not to compare breeding programs against each other, but rather to provide an economic model of each, recognising infrastructure, running costs, capacity to produce families, commercial viability, co-investment with partners across sectors, etc, that will deliver a breeding strategy (breeding design and objectives) for each initiative to allow them to maximise their genetic gains and economic benefits (benefit to cost ratio)."

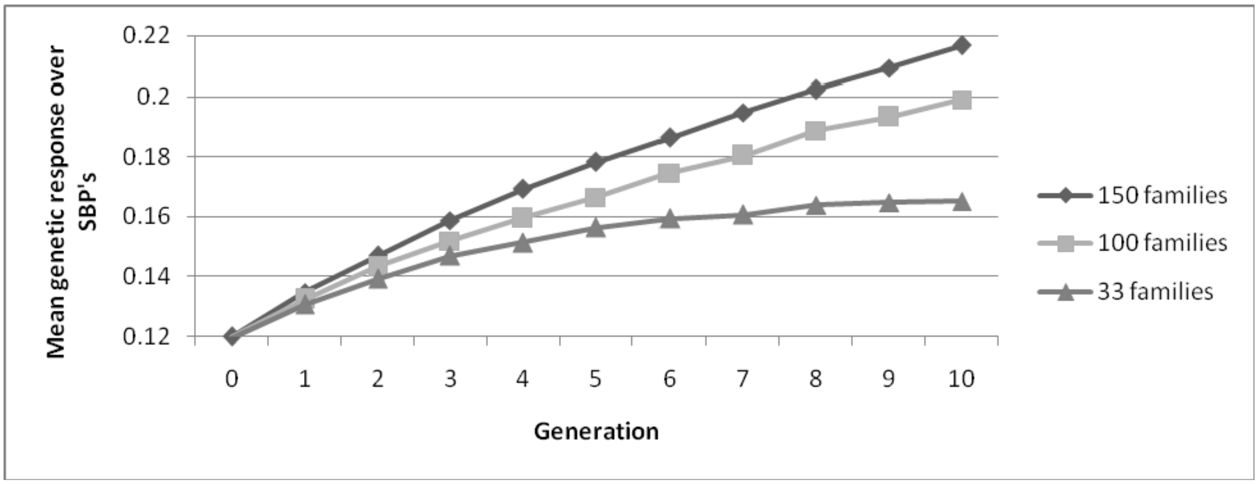
Here we describe how the model that was developed and described in previous sections was used to predict how abalone selective breeding programs could "maximise their genetic gains". The Tasmanian/GSW programs did not wish to contribute data specific to their breeding programs, so we were unable to specifically model these programs. Instead we have determined what the optimum strategy for any abalone breeding program should be in order to give strong genetic gains and high economic benefit-cost. The results here relate to any existing or new selective breeding program for abalone.

A good genetic response was predicted for the growth rate trait (harvest weight in a fixed farming period, Figure 5A). This was expected due to its assumed high heritability and as a higher selection intensity is possible for this trait. With 33 families the trait was initially improved by 9% each generation. But the rate of improvement with 33 families is reduced with each generation of selection, so that by generation 10 there is a very low rate of improvement (1%). This is because inbreeding reduces the genetic variance, and hence reduces the opportunity for making genetic improvement, in the breeding population. With 100 families the maintenance of genetic variance is improved. Growth rate improves by 10% in each of the early generations (2% improvement per generation by generation 10). With 150 families we expect around a 12% improvement in growth rate in the first generation with 3% improvement per generation by generation 10. Using 100 families gives almost double the selection response for growth rate than does using 33 families over 10 generations of selection, while using 150 families adds another 20% improvement over 10 generations on to the response achieved using 100 families. After around 5 generations of selective breeding using 100 families, the grow out time to 120 gm (with shell) would be reduced by almost one year.

Good genetic responses were also achieved for disease resistance, especially when challenge testing to rank families was used in combination with marker information to rank individuals within those families (CRIT3, Figure 5B-D). The advantages from using markers are more pronounced when smaller family numbers are used (Figure 5B-D). This is because there are fewer families to choose between using family breeding values, the selection intensity for family selection is greatly affected, and because it is possible to get added power by being able to choose the best performing individuals within families. Again the genetic response is higher when more families are used.

The variability in the performance of each replicate selective breeding program is a concern when 33 families are used (Figure 6 A and D). Chance plays a larger role in the breeding programs with smaller family numbers. Again this is probably due to the narrow base population used, and narrow subsequent population sizes each generation, when 33 families (66 breeding individuals) are used each generation. Use of the simulation model shows that if you are lucky you might achieve nearly as high a rate of improvement as for the programs with larger family numbers, however, if you are unlucky very little improvement might be made, and in fact the trait might deteriorate with some generations of selection (Figure 6A).

A



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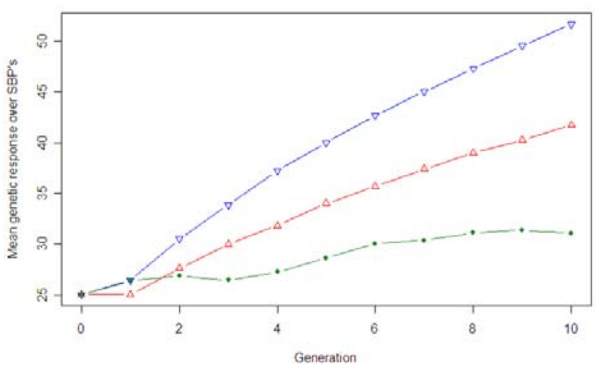

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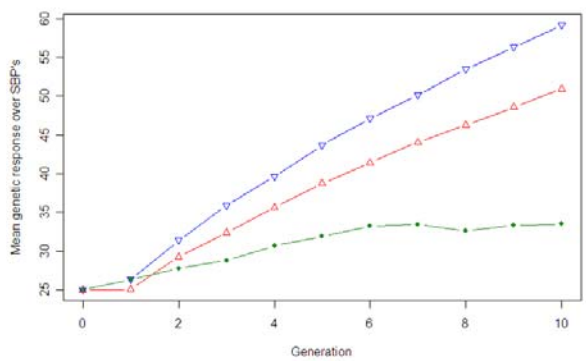

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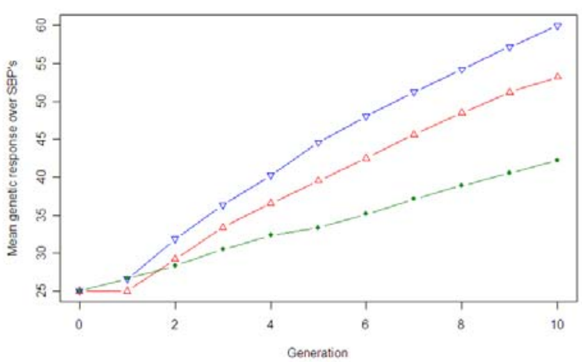


Figure 5. Mean genetic responses in growth rate (harvest weight in kg after a fixed 3 year farming period) (A) and disease resistance/tolerance (B-D) predicted over 10 generations of selective breeding for selective breeding programs (SBP's) of scale B (33 families), C (100 families) and D (150 families). CRIT1 (open red triangles, point up), CRIT2 (closed green diamonds) and CRIT3 (open blue triangles, point down).

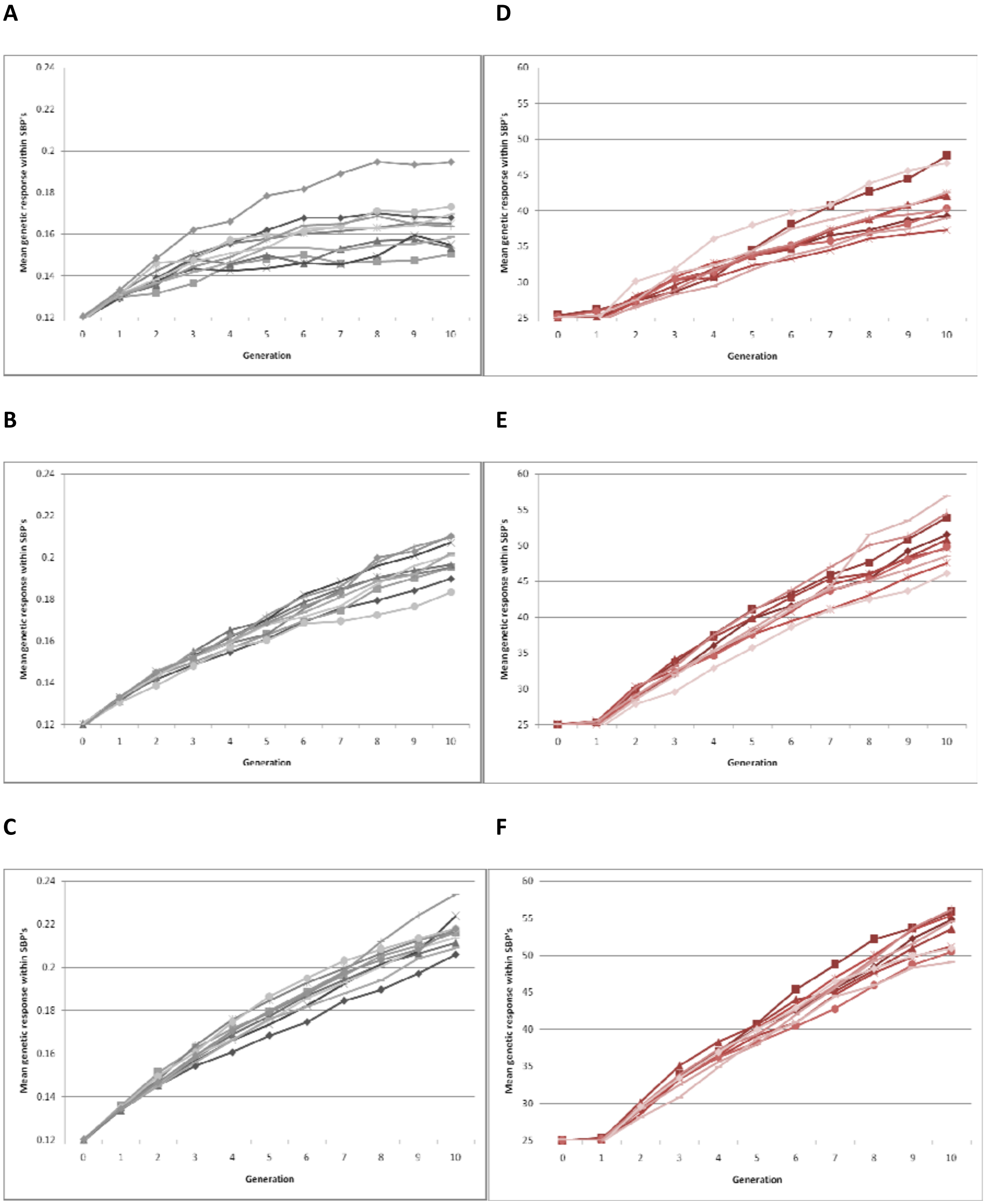


Figure 6. Traces showing the genetic responses to selection for growth rate (harvest weight in kg after a fixed 3 year farming period) (A-C) and disease challenge testing (D-F) predicted over 10 generations for 10 different replicate breeding programs (from repeated simulations) for scale of breeding program A&D (33 families), B&E (100 families) and C&F (150 families).

6.10 Economic impact for the Australian abalone industry

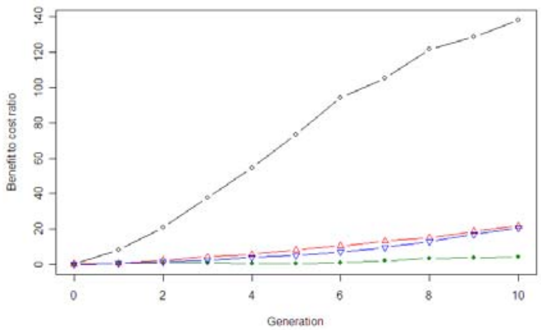
Rationale

This section relates to objective one which was "To model the Tasmanian/GSW program(s) and alternative mainland strategies, and determine the optimal strategy for a unified, centrally coordinated program. The aim was not to compare breeding programs against each other, but rather to provide an economic model of each, recognising infrastructure, running costs, capacity to produce families, commercial viability, co-investment with partners across sectors, etc, that will deliver a breeding strategy (breeding design and objectives) for each initiative to allow them to maximise their genetic gains and economic benefits (benefit to cost ratio)."

Here we describe how the model that was developed and described in previous sections was used to predict how abalone selective breeding programs could "maximise" their "economic benefits". The Tasmanian/GSW programs did not wish to contribute data specific to their breeding programs, so we were unable to specifically model these programs. Instead we have determined what the optimum strategy for any abalone breeding program should be in order to "maximise" their "economic benefits". The results here relate to any existing or new selective breeding program for abalone.

The benefit-cost ratio for the industry of running the selective breeding programs modelled was positive under all scenarios (Figure 7 A-C). This is because we assume that a large proportion of the industry will receive the benefits from the selective breeding program and because the costs of running the selective breeding program are relatively low. The largest benefit-cost ratio is achieved when selecting for improved growth rate (reaching levels of over 200:1 after 10 generations of selective breeding when 100 or more families are used). Similarly, the total added benefit per kg and nominal economic effect on operating income is high, particularly for improved growth rate for selective breeding programs using more than 100 families (Appendix 6, Tables 9-11). After 10 generations of selective breeding for improved growth rate the benefit-cost ratio is around 200:1, the total added benefit per kg of abalone produced is $18 and the nominal economic effect on operating income for the users of the improved stock is over $60 million when 100 families are used. A breakdown of the costs calculated for the base program, and with the application of different selection criteria, are shown in Appendix 6 (Table 11) for a program using 100 families. The projections exclude additional benefits that can be gained by the industry with careful choice of larvae used for distribution (ie calculations are based on the average level of genetic improvement across the 100 families). Benefits can be supplemented by choosing the "best-of-the-best" families for distribution.

A



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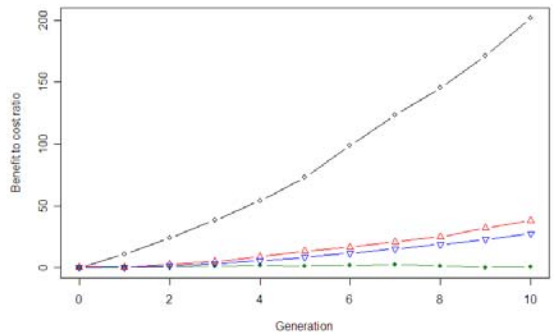

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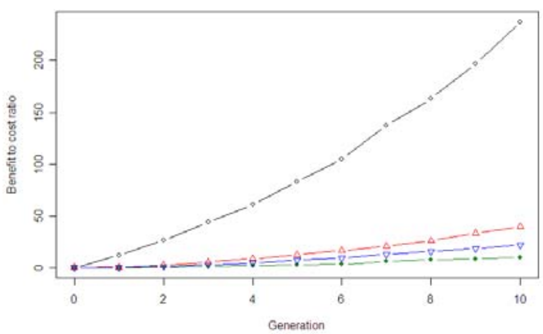


Figure 7. Benefit-cost ratio predicted over 10 generations of selective breeding for selection criteria CRIT1 (open red triangles, point up), CRIT2 (closed green diamonds), CRIT3 (open blue triangles, point down) and CRIT4 (open black diamonds) for scale of breeding program A (33 families), B (100 families) and C (150 families).

6.11 Economic effect of inbreeding depression of fitness

Rationale
The effects of inbreeding depression on fitness could not be modelled in this project, but some corrections could be made accounting for this effect. These corrections affect the "genetic gains and economic benefits" that are modelled under objective one. This section describes how the predictions made by the model developed in previous sections were corrected to account for inbreeding depression of fitness.

Inbreeding depression effects were not modelled (apart for the reduction in variance, caused partially by inbreeding, and its consequent effect on genetic gain Figure 5), but some estimates can be made based on family numbers and size. The extent of inbreeding also depends on the selection intensity applied under each criteria. In the real selective breeding program, inbreeding will be limited (using something like "optimal contributions selection" criteria). This will restrict the selection intensity and genetic response that is achievable in the program.

To derive a ball park figure for the possible effect of inbreeding depression with alternative strategies, let us assume that there is a 2.6% inbreeding depression for body weight with every 10% increase in the inbreeding coefficient. This is approximately what was found for Atlantic salmon (Rye, Mao, 1998) and rainbow trout (Gjerde, et al., 1983). There are likely to be other detrimental effects of inbreeding (eg. disease susceptibility and other traits), but we will ignore those for now. Let us also assume a high selection intensity when we have large numbers of families, and lower selection intensity when we have small numbers of families.

The inbreeding coefficient (F) is the probability that the pair of alleles carried by the gametes that produced an individual were identical by descent. Ie. we need to trace back the pedigree to calculate the inbreeding coefficient. If we start with outbred parents (F = 0) and avoid mating full siblings together in the 2nd generation, but were unable to avoid mating some distant relatives together in the 3rd generation etc. , after two generations of breeding we would expect some individuals would contain some alleles that were identical be descent, and this number would steadily increase as the selective breeding program progressed.

It is complicated to make these calculations, and we would need to make a number of assumptions about the mating design and method use to avoid inbreeding in each of the programs in order to do so. But we can make some estimates of the effect of inbreeding depression by looking at the situation for Atlantic salmon again (Rye, Mao, 1998). Four "sub- breeding programs" were studied by Rye and Mao 1998, and full- and half-sibling families were generated by each of the breeding programs (each sire was mated with 2-7 dams). Each generation gave 104-206 full-sibling groups and 18-110 paternal half-sib groups. Average inbreeding levels did not exceed 5% per generation with this many families and with the avoidance procedures used in Norway. Inbreeding depression for growth rate was around 1.3% for this level of inbreeding. We can estimate the expected rate of inbreeding (ΔF) per generation within the abalone breeding program as $\Delta F \approx 1/(2N_e)$, where N_e is the effective population size. We assume here that we would exclude matings between close relatives, have the same numbers of mating males and females, have equal numbers mating in successive generations and equal family sizes. In the breeding program, some families will perform better than others and we will want to select more animals from these families. In this case we can use a simple approximation of $N_e \approx 4N/(V_k+2)$ where V_k is the variance in numbers picked from each family (Falconer, Mackay, 1996). This variance will depend on the selection intensity we apply, the higher the intensity the greater the variance. I calculated this value for V_k based on data for one generation of one of the replicate breeding programs. When 33 families were used (ie. N=66), 0 - 8 parents for the next generation were chosen from each of the 33 families, and a variance of 5.15 was predicted. In this case, $N_e \approx 4*66/(5.14+2) \approx 37$ and $\Delta F \approx 1/(2*37) \approx 1.4\%$. V_k was observed and an estimate of ΔF was also made for the breeding programs with 100 and 150 families (for 100 families $V_k \approx 6.47$, $N_e \approx 94$ and $\Delta F \approx 0.5\%$, for 150 families $V_k \approx 11.13$, $N_e \approx 91.4$ and $\Delta F \approx 0.5\%$ Table 6). These are conservative estimates of the rate of inbreeding when compared to the realised levels in fish selective breeding programs (eg. Rye, Mao, 1998). The effect of inbreeding depression per generation was estimated for the selective breeding programs using 33, 100 or 150 families based on the effects detected in fish (Table 6).

The correction for inbreeding depression on growth rate shows that the genetic response, especially in later generations, would be affected by inbreeding depression and by a reduction of genetic variance when small numbers of families are used (eg. 33 families, Figure 8). After 8 generations of selective breeding virtually no net genetic response in growth rate is achieved with 33 families.

When the economic effects are corrected for inbreeding depression of growth rate, after 10 generations of selective breeding for improved growth rate the benefit-cost ratio is around 200:1, the total added benefit per kg of abalone produced is $18.23 and the nominal economic effect on operating income for the users of the improved stock is over $65 million when 100 families are used (Table 6).

In our selective breeding programs we will manage the matings as best we can to avoid inbreeding and reduction of genetic variance, or to set a maximum tolerance to the rate of inbreeding and reduction in genetic variance. Avoidance is going to be easier for the programs which have larger family numbers, and therefore we will be able to achieve higher selection intensity for programs using 100-150 families than for programs using 33 families (ie. there will be more opportunities to choose mate pairs that give a strong genetic response while limiting the level of inbreeding). If our selective breeding program consisted of three separate year classes of 33 families, it would be wise to take an opportunity to mate the year classes together at some point. This will reduce the rate of inbreeding in the overall program (although it won't reduce it to the same levels as for when 100 families are used). However, the generation interval in the program might need to be extended periodically in order to mate the year classes together (unless cryopreservation of sperm is possible).

In summary, inbreeding and the effects of inbreeding depression will be far worse, even at lower selection intensity, for the breeding program with 33 families than for the breeding program with 100 families. This is why there are few breeding programs for aquaculture species operating with less than 100 families.

Table 6. Effect of inbreeding depression in growth rate on the economic impact of the selective breeding program.

	Number of families X family size		
	33 * 100	**100 * 100**	**150 * 100**
Possible change in the inbreeding coefficient (ΔF) per generation	1.4%	0.5%	0.5%
Possible effect of inbreeding depression on growth rate ($G_{\Delta F}$) per generation	-0.4%	-0.13%	-0.13%
Predicted economic effects (corrected for inbreeding depression)			
Benefit-cost ratio	134:1	200:1	235:1
Total added benefit / kg production	$12.63	$18.23	$22.55
Nominal economic effect on operating income	$45,300,000	$65,500,000	$81,100,000

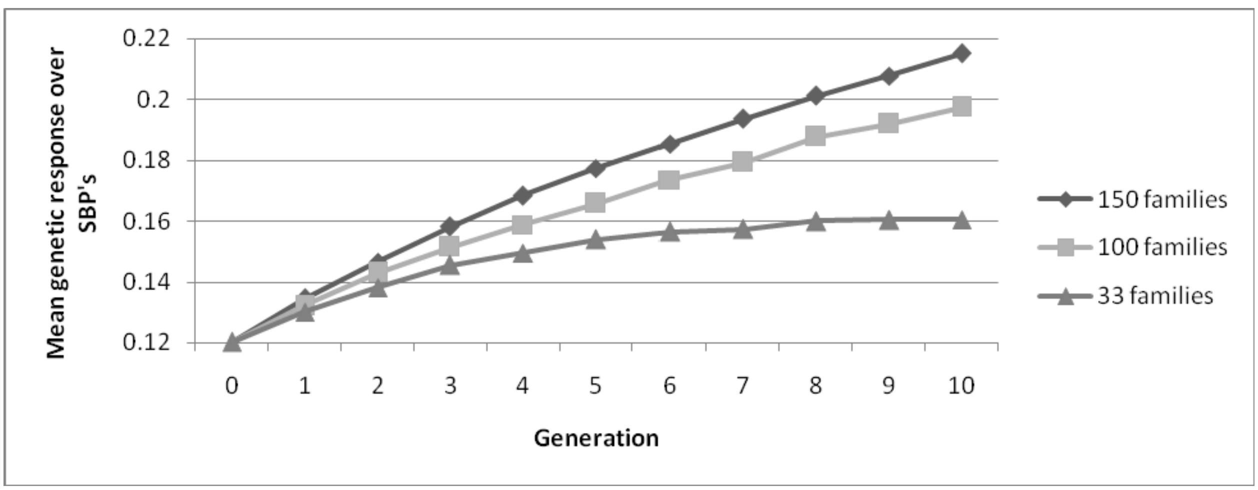


Figure 8. Mean genetic response predicted after correcting for the effect of inbreeding depression on growth rate (harvest weight in a fixed 3 year farming period). The response is shown over 10 generations of selective breeding for breeding programs utilising 33 families, 100 families or 150 families.

6.12 Broad option proposed for running a new centralised selective breeding program

Rationale

Prior sections of the report have addressed objective one by using a bioeconomic model to show how selective breeding programs for abalone can "maximise their genetic gains and economic benefits". It was not necessary to model existing selective breeding programs in order to achieve this objective (the existing selective breeding programs did not wish to contribute the data necessary to model their programs in any case), rather the bioeconomic model was used to determine what approach any selective breeding program for abalone (existing or new) should take in order to maximise benefits.

In this and subsequent sections of the report we are concerned with meeting the fourth objective of the project, in particular the AAGA need for selective breeding to have "capacity to service all industry members". On the mainland Great Southern Waters have developed their own selective breeding initiative to supply their own farm, and other farms on the mainland have been considering doing the same. In this and subsequent sections the report we focus on the development of a new selective breeding program which would have the capacity to "service all industry members" on the mainland, and present an option for commercialisation of such a program.

In previous sections we have predicted that the abalone industry in Australia could substantially benefit from genetic improvement with selective breeding. However, in order for this to happen we need to ensure that

- *a. all farms will have access to these benefits,*
- *b. the costs of genetic improvement are minimised,*
- *c. commercial production imperatives will not override selective breeding imperatives,*
- *d. large numbers of families (>100) could be produced,*
- *e. fast rates of improvement could be achieved,*
- *f. a broad genetic base can be established in the beginning,*
- *g. inbreeding depression of fitness will be limited,*
- *h. a strict timetable and plan for selection and production of families can be followed,*
- *i. biosecurity is both addressed on-site and by receiving farms and*
- *j. tight control of spawning can be achieved.*

It is clear to AAGA that existing Tasmanian and GSW selective breeding programs, by themselves, do not meet all of these requirements. Due to restrictions to the translocation of animals into Tasmania from the mainland, it is not currently possible for a program on the mainland to supply Tasmanian farms, nor is it possible for a Tasmanian selective breeding program to establish a broad genetic base representing natural variation from mainland Australia. It has therefore become apparent during the course of this project that ***there is a need to develop a new program with the aim of benefiting a large proportion of the mainland abalone aquaculture industry.***

To achieve requirements a-j outlined above, and due to the additional strengths highlighted in our SWOT analysis (section 6.2), it would be best if this new program consisted of a single centralised program, operating from a single facility and operating as a separate business entity. Under the current *circumstances, the addition of this entity would provide the best means for fulfilling objective 4 and AAGA's need to have:*

> *"Capacity to service all industry members (including land-based farms without hatcheries and at-sea farms)"*

The new selective breeding program would need to be established in the way we have predicted through simulation in order to fulfil objective 4 and AAGA's need to have:

> *"Capacity to achieve maximum rate of genetic gain for the traits selected"*
> *"Minimum time until the supply of improved stock can meet the demand by the industry"*
> *"Commercial, financial and practical feasibility in the short (5years) and long term (10-20 years), with significant economic benefit to the industry"*

The new entity would need to cooperate with the existing Tasmanian/GSW entities by undertaking collaborative research, implementing common protocols to allow for data sharing and by sharing genetic material where this is possible and desirable. This would allow the industry to fulfil objective 4 and AAGA's need to have:

> *"Capacity for all abalone breeding initiatives to work collaboratively and value-add to each other"*

By operating a program on the mainland that has capacity to supply all mainland farms, and by "closing" the program so that no animals enter the facility after year 1, undertaking strict quarantine, biosecurity and health surveillance measures, and having the facility separated from existing farms, the new program would be extremely well placed to fulfil objective 4 and meet the last of AAGA's needs which is to have:

> *"Capacity to implement biosecurity measures that will meet state agencies' legislative requirements for translocation and result in sustainability of the program (ie. not affected by disease issues)"*

The new selective breeding program could be run as a Pty Ltd company. Farmers would be given an opportunity to invest in the program which would entitle them to shares and a set number of larvae. The program could begin in year 1 with the production of 100 blacklip families and with some production of "unimproved" larvae (blacklip, greenlip and hybrids to fulfil the entitlements of founding shareholders). In the second year the program could produce 100 greenlip families, and again there could be some production of "unimproved" larvae (blacklip, greenlip and hybrids, again to fulfil entitlements of founding shareholders). In the third year there would be no major generation of families and nursery tanks would be largely spelled, and again there would be some production of unimproved larvae (blacklip, greenlip and hybrids) to meet founding shareholder entitlements. In year 4 there would be the first selection of blacklip mate pairs and generation of the first generation of genetically improved families. Production and sale of the first genetically improved greenlip and hybrid larvae could occur in year 4. etc. The broad scheme for running the program is shown in Figure 9.

Larvae for sale would be tailored to meet customers' preferences for species, colour and patterning and this product will represent the "best of the best" families created that year. The benefits we calculate in this scoping study are conservative in that we assume that the performance of animals that are supplied to the industry is the same as the mean performance across all the families generated in the breeding program.

A general plan showing necessary facilities and the flow of proposed activities is shown in Figure 10. After animals are tagged the families would be pooled into larger tanks. Some tagged animals from every family would be sent for performance testing on farms. This would allow assessment of the relative performance of families in different growing environments and also provides a backup source of improved genetic stock in the event of disaster striking the breeding nucleus. There would also be an opportunity for farmers to compare (benchmark) their own farms performance with the average farm (note, growers will not be given access to specific performance data for other farms).

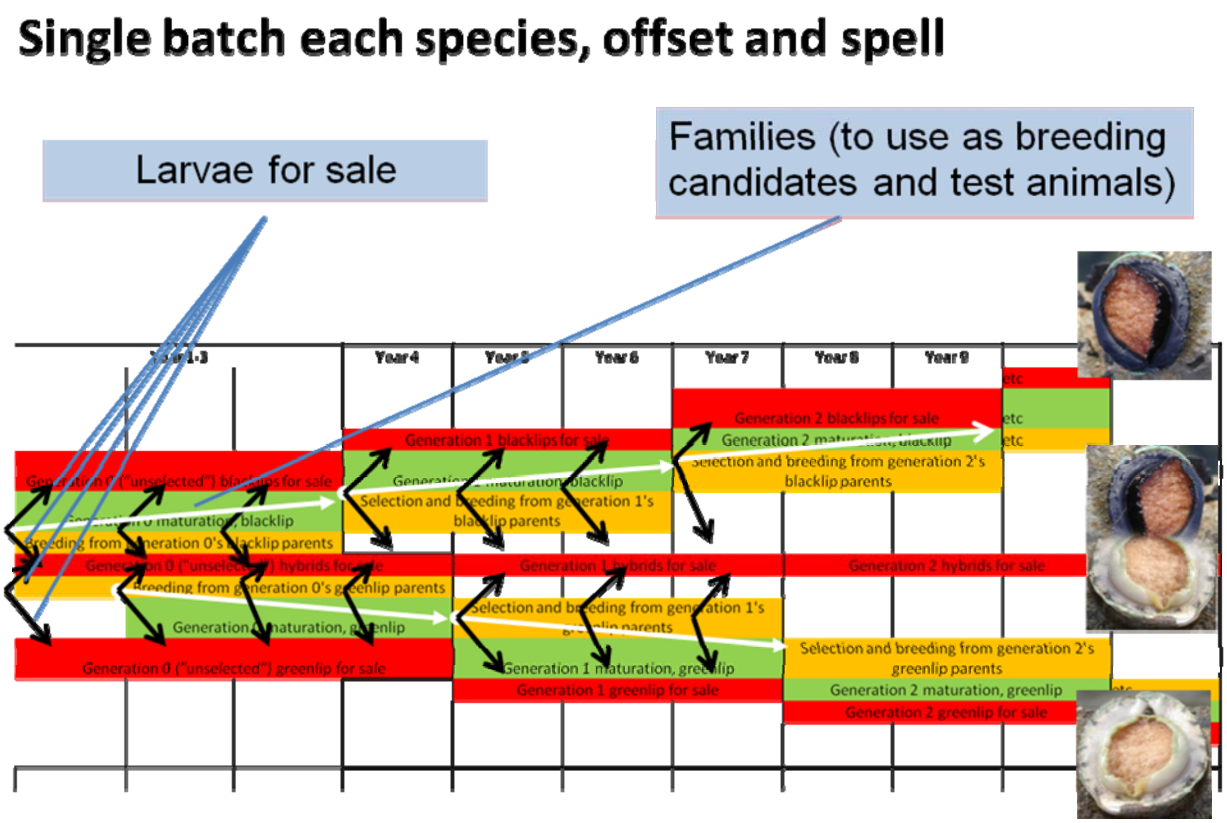


Figure 9. Broad option selected for running the selective breeding program.

6.13 Commercialisation strategies, investment and pricing

Rationale

In the previous section we described the need and broad plan for a new mainland selective breeding program. This section describes a strategy for commercialisation of the new selective breeding program for the mainland and address the need stated by AAGA that selective breeding programs have "commercial, financial and practical feasibility in the short (5years) and long term (10-20 years), with significant economic benefit to the industry".

The development of a commercialisation strategy was flagged in the original project methods. Because it became evident during the course of the project that there was a clear need and desire by a number of mainland farmers to develop a new selective breeding entity, it was logical to progress the business plan for this entity further than was envisaged in the original proposal. Appendix 7 contains a business proposal for this entity. The figures contained in this appendix are referred to in the commercialisation strategy. Commercialisation strategies developed for any new selective breeding entities would be relevant and could be adopted by existing initiatives to help improve their short- and long-term commercial feasibility.

A number of pricing and investment strategies were tested using the simulation model for the selective breeding program (Appendix 5). Here I will focus on the most promising strategy tested so far. This strategy has been turned into a stand-alone business proposal (Appendix 7).

We should consider selective breeding as a potential "enabler" that allows the farmer to increase his revenue stream by gaining access to the benefits that come from, for instance, stock that has a faster growth rate. We have already seen what those benefits could be for the abalone industry in Australia if there were a single selective breeding program supplying a large proportion of the industry (described in detail in section 6.9). If the industry does not invest in some way in genetic improvement, then there is no opportunity for individual farmers to realise these future benefits.

Here we propose a sliding scale of investment cost per farm tonnage depending on the total level of industry participation in a selective breeding company. A guide to this sliding scale is shown in Table 1 of Appendix 7 and we present the business case for a starting participation of five farms (250 tonne current production) in the business proposal (Appendix 7).

Under the assumptions for industry participation used in modelling the program, we chose a pricing/investment scenario that would give the selective breeding program a positive cash flow in the early years (when there is little differentiation of selectively-bred v. "unimproved" stock, ie. genetic improvement is only beginning to be made), and would give investors benefits both in terms of early access to genetically improved stock and in the form of discounts (payback on investment) later down the track. The discounts effectively reduce the price paid per million larvae for the shareholders. To illustrate the benefit for investors, we have considered how a farm producing 100 tonne/year might be affected if it purchased and invested in selectively bred stock from the selective breeding program.

The program would begin with donation by farmers of their favourite broodstock. All donated broodstock would have a clean health record. Depending on the genetic diversity represented in these broodstock there may not be a need to sample other broodstock from the wild. These founding broodstock will be used to produce the first families (candidates for selective breeding). In the first 3 years of the selective breeding program, farmers will be able to purchase larvae from crosses between these "favourite" animals. I will refer to this as "unimproved larvae", but most of these animals will have been considered "favourites" because the farmers believe that these animals have the "best genetics". It will be in the farmers' interest to donate these animals so that they can be sure that their preferred genetics are represented in the breeding program. After this initial input of animals in year 1, the program will be closed, that is no further animals will be translocated into the breeding nucleus facility. One hundred males and 100 females would be needed to generate 100 full-sibling families for each species (blacklip and geenlip) each generation (ie. 100 families was chosen because of the high benefit-costs, likely effects of inbreeding depression with smaller family sizes, capture and maintenance of genetic variation that can be used as the basis for future genetic improvement and other practical considerations described in the above sections of this report).

During the company's start-up period, farmers will be given the option to buy founding shares in the selective breeding company. This will entitle these farmers to larvae from the selective breeding program. It will also be possible to invest in the breeding program without purchasing larvae (if this occurs, we will need to provide dividends to benefit investors who do not purchase larvae). It may also be possible for the breeding company to attract government start-up grants etc that will add to the total investment. Assuming only farmers invest, a set dollar value worth of shares will entitle the farmer to 1 million larvae (fifty larvae to seed every kg of production). In the business proposal (Appendix 7) we assume in our projections that through this initial investment period enough larvae to supply 33% of the Australian industry will be bought (in the first 3 years this larvae will be derived from matings between "unimproved favourite" animals, after this larvae will be derived from matings of selectively improved stock). Projections of larval sales to these investing farms are shown in Figure 3 of Appendix 7. After the first year the opportunity to invest in the selective breeding program will be closed. The price per million larvae will be maintained with each subsequent generation of selection. Founding shareholders will receive discounts (Figure 7 of Appendix 7) that effectively subsidise the price of buying larvae (Figure 8 of Appendix 7). Non-investors will be able to purchase larvae but will not be entitled to discounts.

The net present value of investment in the selective breeding program under this scenario is shown in Figure 5 of Appendix 7. We have also assumed for this calculation that it costs around $100,000 to start up the business (eg. project scoping costs etc.). The net present value measures the excess or shortfall of cash flows in present value terms once financing charges are met. The net present value of the selective breeding program is positive at year 9, and remains positive after this. Profit/loss predictions for the selective breeding company are shown in Figure 4 of Appendix 7. Profits by the company steadily increase with growth of participating shareholders and with sale of excess family material for processing. All profits are paid out as discounts (subsidizing the costs to founding investors). **These are conservative projections which assume that growth of the revenue stream is due solely to projected growth in the level of production of those five mainland farms who commit. That is, the projections**

exclude potential offset of expenses from government grants, growth in revenue stream due to stimulation of higher production levels and demand among users, more Australian farms joining and buying from the program and/or export sales. Internal rate of return on investment is negative in the first 3 years, and low for the first few years after that, if we assume there is a low (33%) uptake. But internal rate of return is high (up to 50%) after several years. **We have not budgeted for expense offsets that might come from government grants, other sources of investment money or from equity arrangements which reduce lease costs.**

The cost of the larvae for a farm producing 100 tonnes per year is shown in Figure 6 of Appendix 7. Discounts earned by the 100 tonne farm (Figure 7 of Appendix 7) will reduce the net cash outlay (Figure 8 of Appendix 7) for this farm over time. After year 3 the 100 tonne farm is paying less for the larvae than it would in operating costs if it were to attempt to run its own less efficient selective breeding program (assuming a small program utilising 32 families as calculated by Mark Gervis for the 1st selective breeding program, Figure 8 of Appendix 7). Also, available tank space on the farm could be fully utilized for production (no need for family generation). As well as receiving a discount, the investors/customers of the selective breeding program benefit from growing the genetically improved stock on their farms. Figure 9 of Appendix 7 shows the benefit in terms of total added production value expected for a farm with a steady production of 100 tonne per year. The predictions made by the simulation model are very similar to those made by Mark Gervis from the improvement observed after 1 generation of selection on growth rate with the past selective breeding program (Mark predicted a gross benefit of $4.2 million to a 100 tonne farm accumulating over 10 years, the model predicts a net benefit of $3.4 million over a similar time frame). Given the rate of genetic improvement predicted, the benefits to be realized by the 100 tonne farm growing the selected stock would pay off the total investment made by the 100 tonne farm in the selective breeding program around year 8 (Figure 10 of Appendix 7). By year 9 the total benefits derived from growing genetically improved stock would be $1.4 million for a 100 tonne farm. These benefits from the program will provide incentive for farms to expand. In expanding their operations, these farms will receive even higher benefits, in terms of total added benefit, from purchasing the selectively bred stock. All-in-all, a farm producing 100 tonne per year could expect a large, and growing, return-on-investment after year 6 (Figure 10 of Appendix 7).

6.14 Conclusion for commercialisation

Under the assumptions for industry participation used in developing the draft business proposal, founding shareholders investing in the company would be entitled to 1 million larvae for around every $21,000 worth of shares purchased. Founding shareholders purchasing larvae from the breeding company would be advantaged as they would receive discounts that would offset the cost of larval purchase. By year 4 the net cash outlay per year on improved larvae would be less than the operating costs of a farm generating a small number of families for selective breeding. Founding shareholders and other purchasers of larvae would also benefit from growing the genetically improved stock (ie. faster growth rate, improved feed conversion ration etc). A business proposal detailing a case study, assumptions, conditions and risks has been prepared (Appendix 7). The business proposal presents a conservative case study which assumes that growth of revenue streams for the company is due solely to projected growth in the level of production of those five mainland farms who commit as investors. **That is, the projections <u>exclude</u> potential offset of expenses from government grants, growth in revenue stream due to stimulation of higher production levels and demand among users, more Australian farms joining and buying from the program and/or export sales.** For a 100 tonne farm, the genetically improved stock would yield around $1.4 million in total added production value by year 9. Benefits to those 100 tonne farms investing and purchasing selectively bred stock steadily increases with each new generation of selected stock. Annual returns of over $1 million per annum would be expected for a 100 tonne farm by year 19. The returns predicted far outweigh those that might be achieved by individual farms running their own selective breeding program in isolation. The commercialisation strategy developed for the new selective breeding entity could be adopted by existing initiatives to help improve their short- and long-term commercial feasibility.

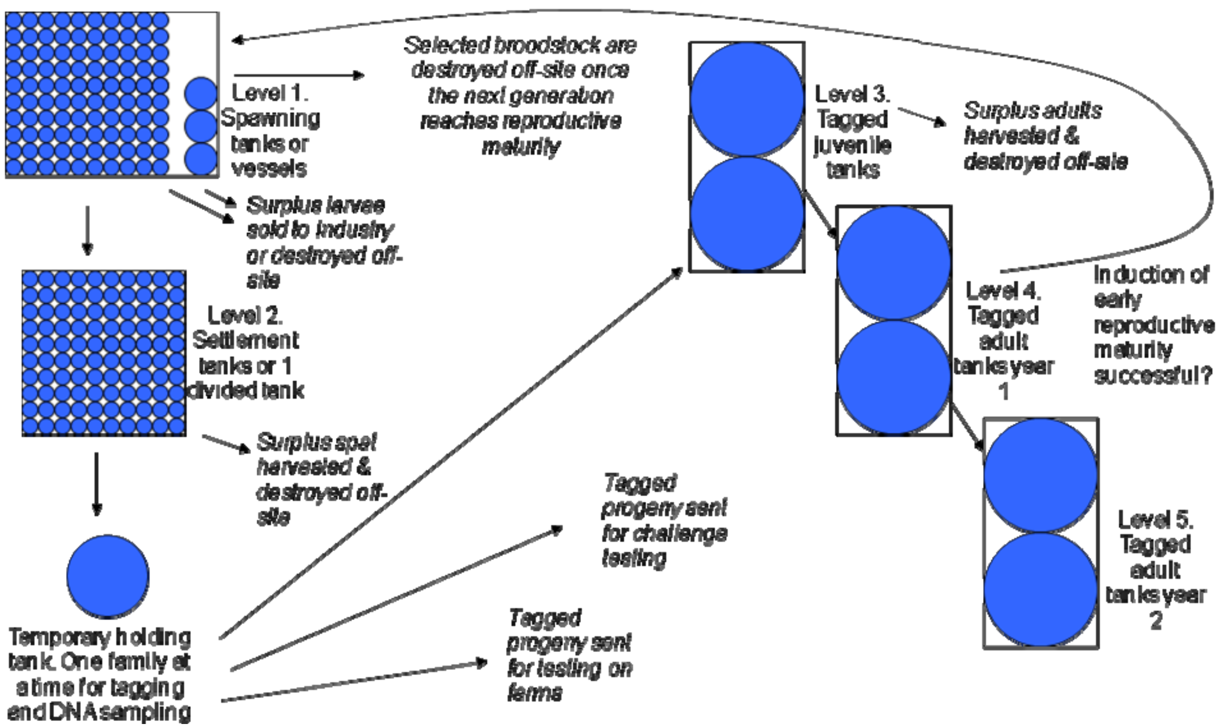


Figure 10. Design and set up for the abalone breeding nucleus.

6.15 Options for location a centralised breeding facility

Rationale

In order to meet objective 4 and to "achieve the objectives of AAGA", selective breeding programs need to have a "commercial, financial and practical feasibility in the short (5years) and long term (10-20 years), with significant economic benefit to the industry". "Practical feasibility" is conditional on a suitable option being available for the location of the selective breeding facility.

Advantages and disadvantages of two options for the location/facility for the centralised breeding program have been considered and are given in Table 7. Further options need to be explored. The two options shown in the table are ones for which some preliminary data was available and industry participants wished to explore further.

Table 7. Options for location of the centralised breeding facility.

Potential venue	+ve	-ve
SARDI West Beach facility	• Staff with experience relevant to family generation and abalone production close on-hand • High biosecurity standards proposed • Temperature regulation proposed • Distance from existing abalone populations at least 10-15km • No abalone farms in vicinity • Many necessary protocols and facilities are already in place with regard to biosecurity, power backup, alarms etc. • Support staff on-call 24 hrs a day 7 days a week in the event of problems. Automatic alert systems in place. • Good scientific and technical working environment for breeding program staff. • Severe ramifications for SARDI's reputation if a problem occurs • Confidence in management practices by industry, chief veterinary officers and state governments. May make it possible to obtain clearance for translocation where otherwise it might be difficult. May influence policy decisions affecting the selective breeding program's business. • Security of lease. Less likely to be sudden sale or shutdown of facility. • Security patrols, fencing, and sign-in protocols for visitors etc in place • Proximity to airport and courier companies for rapid transport of larvae • Associated facilities and equipment (eg. laboratories, autoclaves, etc).	• Cost? • Numbers of people working in and visiting facility and associated risk of disease transmission • Need to invest in specific nursery and grow out tanks, but this would be covered by cost of lease.

Bay city abalone, Port Phillip Bay	• Site with appropriate licences. • Facilities including office, spawning area, large nursery facilities and growout tanks. • Large heat unit in place. • Potential to be biosecure quite easily • Flexibility in terms of lease • Amenable to equity arrangement in order to reduce lease costs	• Would need to adapt to give capacity for recirc. Covered by the cost of the lease? • Would need to modify tanks for nursery. Covered by the cost of the lease? • Security would need to be upgraded. Covered by the cost of the lease? • In Port Phillip Bay may be issues if virus gets to Bay even if facility never suffers from it. • Would require staffing from scratch and staff would need to be able to carry out maintenance activities.

7. Benefits and adoption

Refer to detailed results of scoping in sections 6.9 to 6.14. With an initial adoption rate of 50% growing to 95%, and production growing at 100 tonne per year to 3,800 tonne, after 10 generations of selective breeding we predict a benefit-cost ratio of around 200:1, total added benefit per kg of abalone produced would be $18 and nominal economic effect on operating income would be over $60 million per annum.

8. Further development

Research to overcome key constraints. The report scores research areas on the basis of benefit to the selective breeding program, likelihood of success and urgency. This gives us an indication of the order for prioritisation. The next step might be to use the simulation model to predict what the economic benefit from these research areas might be. The Seafood CRC/AAGA also need to agree on the areas that they would fund and proposals need to be drafted to address these areas.

Commercialisation of a new centralised selective breeding program on the mainland. There is a need to pass on the benefits from selective breeding to a large proportion of the industry. For the Australian abalone industry to benefit substantially from the genetic improvements made with selective breeding we need to ensure that:

- all farms will have access to these benefits,
- the costs of genetic improvement are minimised,
- commercial production imperatives will not override selective breeding imperatives,
- large numbers of families (>100) could be produced,
- fast rates of improvement could be achieved,
- a broad genetic base can be established in the beginning,
- inbreeding depression of fitness will be limited,
- a strict timetable and plan for selection and production of families can be followed,
- biosecurity is both addressed on-site and by receiving farms and
- tight control of spawning can be achieved.

It is clear to AAGA that existing selective breeding programs, by themselves, do not meet all of these requirements and that a new breeding entity is needed. A draft business proposal for the selective breeding company has been created (Appendix 7) and will be put to members at the AAGA workshop in August. The business proposal outlines the benefits, assumptions, conditions, risks and potential cost offsets for the company and presents a case study for a 33% industry participation as founding investors. If the project is to go ahead, the following sequence of events needs to occur:

- Expressions of investment interest will be sought (first round collected by 1 October 2008).
- Government startup and research investment sought. FRDC Tactical Research Fund grant sought.
- After the initial round of expressions, follow up calculations and presentations will be made to remaining industry participants to see if further interest can be attracted.
- Discussions need to be held with owners of potential venues for the program and with State Government Animal Health and Primary Industry departments.
- Investment contracts signed and the first years investment funds allocated by the farmers in January 2009 (paid by quarterly installments).
- Upgrade of the chosen facility would need to occur by February 2009.
- Staff would begin work 1 February 2009.
- Translocation of founding broodstock into quarantine would need to occur by the end of April 2009.
- First larvae distributed to founding shareholders November/December 2009.

9. Planned outcomes

- Based on the simulations performed for the project the abalone aquaculture industry is now able to make informed decisions on how to achieve their objectives for the long term development of national selective breeding programs to achieve significant economic wealth (sections 6.10 to 6.14).
- Areas of collaboration needed to add value to each program, and standardisation of procedures needed to ensure collaboration is achievable, have been identified (sections 6.1,6.2, 6.4 and 6.4). This will mainly occur through open research collaboration on areas identified as priorities for selective breeding (section 6.4) and through sharing of information between the programs. Sharing of a common database system by the programs would provide a solid grounding for future collaboration. As genetic material is unlikely to be exchanged between existing and new programs, collaboration will occur through joint research projects (development of common tools, such as common databases, and shared knowledge).
- Key researchable constraints to the implementation of the breeding programs have been identified (section 6.4). These constraints are addressed by future research projects, and solutions are provided to and implemented by the selective breeding programs.

10. Conclusion

Past experience has highlighted the need for and benefits from having selective breeding treated as a business in its own right. When selective breeding is practised by individual farms, the costs of producing genetically improved seed will be higher than the costs of purchasing from a centralised program. There are also dangers that commercial production pressures come before family production, that genetic improvement will be sub-optimal and that inbreeding depression effects on production and fitness will be high. Centralised selective breeding programs can be a strong "enabler" for an aquaculture industry, and can stimulate the expansion of existing farms and lead to the entry of new players. Industries overseas (eg. Atlantic salmon in Norway) have realised that without such programs and the improved efficiencies in production that they create, that it would have been difficult to survive in the face of falling prices and increasing international competition. Selective breeding is a complex business involving many biological, practical and economic influences. Bioeconomic models are valuable tools for optimising the design and commercialisation of such selective breeding programs. Such models need to be grounded with reliable industry data, SWOT and risk analyses such as has been collected from the abalone industry in this scoping study (sections 6.1, 6.2, 6.4 and 6.7). Different scenarios (section 6.7) and their effects need to be tested. Research to overcome key constraints will be of major importance to such businesses, and research projects, as well as research providers, need to be clearly identified, prioritised and funded in a way that facilitates selection and minimises risks for the centralised selective breeding program (section 6.5). Application of a bioeconomic model has enabled us to optimise the design of selective breeding programs for abalone in order to achieve strong genetic gains (section 6.9), while limiting the negative economic effects of inbreeding depression (section 6.11), giving high benefits-costs to the industry (section 6.10), ensure cash flows and profitability of the selective breeding business (sections 6.13 and 6.14) and make an attractive case for investment by the abalone industry into a company which runs a centralised selective breeding program (sections 6.13, 6.14 and Appendix 7). The scope for a profitable, unified and highly beneficial program is high, all that is needed is investment and commitment by the industry to make it happen.

11. References

Anonymous, 2007. Victorian abalone aquaculture translocation protocol, Fisheries management report series. The State Goernment of Victoria, Department of Primary Industries, Fisheries Victoria, Melbourne, pp. 1-31.

Bondad-Reantaso, M.G., F., B., 2005. Molluscan pathogens of concern in ASEAN. In: NACA (Ed.), The way forward: Building capacity to combat impacts of aquatic alien species and associated transboundary pathogens in ASEAN countries. Network of aquaculture centres in Asia-Pacific, pp. 179-195.

Elston, R.A., Cheney, D.P., 2004. Shellfish high health program - Building success through health management and disease prevention. World Aquaculture 35, 48-52.

Falconer, D.S., Mackay, T.F.C., 1996. An introduction to quantitative genetics. Addison Wesley Longman Limited, Edinburgh Gate, 464 pp.

Gavine, F.M., Ingram, B.A., Hardy-Smith, P., Doroudi, M., 2007. Biosecurity control measures for abalone viral ganglioneuritis: A code of practice. Fisheries Research and Development Corporation and The State of Victoria, Department of Primary Industries, Alexandra, pp. 1-31.

Gjerde, B., Gunnes, K., Gjedrem, T., 1983. Effect of inbreeding on survival and growth in rainbow trout. Aquaculture. Aug 34, 327-332.

Ingram, B.A., Gavine, F.M., Lawson, P., 2005. Fish health management guidelines for farmed murray cod., Fisheries Victoria Research Report Series No 32. The State of Victoria, Department of Primary Industries, Alexandra.

Robinson, N.A., Hayes, B.J., 2008. Modelling the use of gene expression profiles with selective breeding for improved disease resistance in Atlantic salmon (*Salmo salar*). Aquaculture. 285, 38-46

Rye, M., Mao, l.L., 1998. Nonadditive genetic effects and inbreeding depression for body weight in Atlantic salmon (*Salmo salar* L.). Livest. Prod. Sci. 57, 15-22.

Thodesen, J., Grisdale-Helland, B., Helland, S.J., Gjerde, B., 1999. Feed intake, growth and feed utilization of offspring from wild and selected Atlantic salmon (Salmo salar). Aquaculture. Nov 180, 237-246.

12. Appendix 1. Intellectual property

All of the information generated from this scoping study should be made publically available to the industry. The bioeconomic model software program that was used in this project remains the property of Nofima (Akvaforsk-Fiskeriforskning) in Norway.

13. Appendix 2. Staff

Principal Investigator Dr Nick Robinson. Co-investigators Xiaoxu Li and Nick Elliot. Other research investigators, Graham Mair, Martin Millar, Peter Kube, Medhi Doroudi and Steven Clarke. Industry participation Ann Flemming, Mark Gervis, Jonathan Lillie, Nick Savva, Geoff Penfold, Justin Harman and Shane McLinden.

14. Appendix 3. Details of 1st workshop held 23 May 2008, 10.00AM-4.30PM

A workshop was held at Lempriere Fox & Lillie, Level 4, 166 Albert Road, South Melbourne on the 23rd of May 2008 to seek input to help address the issues related to this milestone for the project. Participants at the workshop included Mark Gervis, Nick Savva, Ann Flemming, Geoff Penfold, Justin Harman and Jonathan Lillie (representing the abalone industry), Nick Elliot (representing CSIRO), Xiaoxu Li (representing SARDI) and Martin Millar (representing the Seafood CRC). In all there was a good representation of farmer and researcher views from South Australia, Victoria and Tasmania. Apologies and interest in the results of the workshop was expressed by Bruce Green, Paul Clark, Tom Hyde, Anton Krsinich, Tim Rudge and Graham Mair.

The purpose of the workshop was to

- Collect information from that would allow us to model alternative strategies for running a selective breeding program and determine which strategy is optimal in terms of genetic gains and economic benefits
- Perform a SWOT analysis on the selective breeding program
- Perform a risk analysis on the selective breeding program

The workshop was facilitated by NR. The role of the facilitator was also to give the participants a better understanding of

- what has happened in the past?
- what are the broad options?
- what are the SWOT's?
- what needs to happen in the future?
- how are we going to make it all work?!

The workshop agenda was as follows, but due to lack of time we were unable to fully discuss SWOT's and perform a risk assessment together on the day. However, points of relevance to the SWOT and risk assessment were raised during the day and processed by the PI after the workshop.

10.00 Welcome. Project objectives. (Nick Robinson)

10.05 Genetic improvement and the Australian Abalone Industry today. (Ann Fleming)
10.20 Past selective breeding program. Practicalities, costs and benefits. What was learnt? (Mark Gervis)
10.35 Designing and modeling selective breeding programs. Trait prioritisation, cost, benefits and profits. (Nick Robinson)
11.05 Trait prioritisation exercise (All)
12.30 **Lunch**
13.00 Continuation/summary of trait prioritisation (All, Nick Robinson)
13.15 Discussion of broad options for modeling (All)
13.30 Check off economic parameters (input for the model) (All)
14.00 Summary. What will be modeled. Options? Best vs worst case comparisons? (Nick Robinson)
14.30 Strengths, weaknesses, opportunities and threats for breeding program business (All)
15.00 **Break**
15.15 Risk assessment for breeding program. Research needed? Available SOPs addressing risks? SOPs needed?
15.45 Summary and actions
16.30 **Close**
Summary and actions

15. Appendix 4. Parameters used as input for the bioeconomic simulation model.

Parameters shaded red are those that were varied in different runs of the simulation model, those shaded grey or blue are those parameters that are either not relevant to this particular study or not considered due to constraints in the scope of the project.

Economic parameter description	Abreviation	Estmate
Total slaughter weight of entire abalone aquaculture industry in Australia (kg with shell?)	*totalsw*	800000 growing at 100 tonne per year into forseeable future)
Proportion of industry assumed will use selectively bred stock	*psb*	0.75 (going to 0.95 slowly over the 10 gens) or 0.5 (going to 0.95 fast in 2 generations)
Average target weight at slaughter (kg with shell? Ie. is the price paid for whole abalone with shell?)	*atw*	0.12
Average time until slaughter (in years)	*atts*	3
Average "harvest" price ($/kg with shell?)	*pkg*	30 farm gate
Total feed conversion ratio from time put in grow-out tank to slaughter (kg feed/kg abalone)	*fcr*	1.8
Average price ($/kg) of all feed fed from time set in tank to time of slaughter (assumes	P_{feed}	2.75

animals graze algae prior to grow out at cost estimated below)		
Anticipated antibiotic/treatment cost per non-selected fish (if used)	*cab*	0
Proportional reduction in antibiotic/treatment use as a result of the protection provided by selection for resistance (if used)	*abred*	0
Predicted proportion grow-out survival in non-selected fish	*surnonsel*	0.8
Market value ($) per fish at time before set in tanks for grow-out	P_{fish}	0.37 (2 cents per millimeter)
Expected average weight of all diseased/dead non-selected fish removed in kg	W_{dead}	0.05
Labour cost ($) of carcase removal/kg dead abalone	lccr	0.04 (summer KIAB 50% labour costs cleaning and morts)
COSTS FOR SELECTIVE BREEDING PROGRAM		
Cost ($) of genetic marker or GE tests per fish (includes laboratory labour)	$Cost_{ge}$	5
Cost ($) of challenge test per fish (includes VESO labour and transportation, calc from cost of $/X kg tank of X g fish)	$Cost_{chal}$	10 (20 per animal if pedigreeing)
Cost of labour ($/fish) required to sample fish for testing (to identify, sort and measure/weigh animals)	*costlabour*	0.02
Added costs ($/fish) such as consumables required to sample the fish for testing (eg. consumable equipment associated with the measurement/weighing)	*costadd*	0.002
Number of species	*nspecies*	2
Number of overlaping year classes (if 3, then all stages are costed in each year, if 1, the costs of all stages are divided by 3 each year. ie. assumes 3 years for each generation.	*nyrclass*	1 or 3
Cost of tags and tagging per family	costtag	0.1
Cost of tagging (labour cost/ family)	costlabtag	270
number needed to be tested on farms (per family and per farm)	nfarmtest	20, 50, 100
number of farms where animals will be tested	nfarm	10
number of farms buying larvae for growout from selective breeding program	nfarm2	7 (for 50%)
Cost transport (spat) for on-farm testing per participating farm	costtrans1	100
cost transport of larvae to farms for sale (per farm)	costtrans2	100
cost per annum of quantitative genetics analysis	costquangenanal	30000
cost of board of management per annum	costbm	0
cost of ongoing business registration and accounting per annum	costaccount	5000
predicted proportion of animals lost during grow out phase (after tagging)	plgout	0.25
predcited proportion lost from settlement to tagging	plspta	0.25
predicted proportion lost from spawning to settlement	plhatch	0.75
cost of power needed to run four slab tanks	powergout	3360 $70 per month per slab = 840 per year per slab (make it 4 slab tanks now)
cost of power needed per family of spat	powerspta	30
cost of power needed per family in the hatchery	powerhatch	2
average total labour cost **ON FARMS** per kg of production	lkfp	7
costs of labour for a manager and additional staff (apart from those budgetted for below) to keep the whole program running, handle customers etc.	labourSBPmanager	160934
cost of labour needed to clean and service two grow out tanks	labourgout	2400 (2 tanks) Make it 4 slab tanks now ie. 4800
cost of labour needed per family of spat	labourspta	160
cost of labour needed per family in the hatchery (ie. spawn and fertilise according to preferences for mating).	labourhatch	120
Cost of other overheads to run two slab tanks (list amount and what they are)	costoohgout	0

Cost of other overheads to run tanks per family of spat (list amount and what they are)	costoohspta	0
Cost of other overheads to run tanks per family in the hatchery (list amount and what they are)	costoohhatch	0
Annual costs of special permits needed	costpermits	1000
Any other additional costs (per annum) that will be incurred because of the selective breeding program (eg. additional energy costs for temperature control?)	costanyadd	30000
price to grow algae for seeding plates (assuming this doesnt change much with numbers of families)	feedspta	50
starting price fetched for unimproved larvae (per litre or per million?)	startprice	See scenarios compared in report
total number of million of larvae needed to give 1 kg of production	larvtokg	0.00005
NOT USED NOW ie SEE LARVTOKG ABOVE starting volume sold for unimproved larvae (per litre or per million)	startvolsold	35 (at 50%?)
starting price fetched for unimproved mature broodstock (per animal)		
starting volume sold for unimproved mature broodstock (number sold)		
margin on improvement made by SBP (ie. 0.1 means that for every $1 increase in total added benefit per kilo due to genetic improvement the SBP charges 10 cents/kg extra)	impmargin	0.1
projected increased uptake (sales) with genetic improvement (ie. 0.01 means that for every $1 increase in total added benefit per kilo due to genetic improvement results in 1.01 * volume sold)	impuptake	0
cost of leasing a facility (per year). n.b. If leased then landlord pays for and supplies all necessary infrastructure (tanks, pumps etc)	facilityleasecost	50-70K. Ie say 60000
cost of either purchasing or building a facility that meets the needs. n.b. If purchased/built then costs must cover all necessary infrastructure	facilitypurchasecost	0
Cost broodstock purchase	broodpurch	
Cost broodstock transportation	broodtransp	
Cost broodstock quarantine	broodquar	
Cost broodstock maintenance until and over spawning season	broodmaint	
Business registration	regstrnacconting	
Calculate "start up" capital injection and costs	startcapital	
Capital costs needed (any additional costs to either upgrade a farm, multiple farms or existing research facility)		
Cost of scoping the business and follow up work to get it started	businessscoping	100000
Broodstock and conditioning system	add on to existing farm so add	50000
Larval equipment		12000
Split nursery tanks		80000

Genetic parameter description	**Abbreviation**	**Estmate (disease resistance)**	**Estimate (growth rate)**
Number of families to generate each generation. This influences family size (depending on selection intensity).	famnum	33, 100 or 150	33, 100 or 150
Family size	famsize	100	100
Number of times to repeat whole selective breeding program	repnum	10	10
Number of generations over which each selective breeding program will run	gennum	10	10
Number of progeny to be challenge tested from each family for estimation of parental breeding values	ctnum	20	20
Correlation between gene expression phenotype and actual challenge test phenotype.	corgec	NA	NA

Correlation between the genetic effects behind the gene expression trait and the challenge test trait	r	NA	NA
Might want to loop through different values for r eventually (would need to set up the rr and r values properly so r goes from 0.1 to 1.0)	rr	NA	NA
Heritability of trait	her	0.1	0.3
Genetic correlation between traits (ie. the correlation of breeding values. Need to provide a matrix)	ra		
Phenotypic correlation between two traits (Need to provide a matrix)	rp		
Starting population variance for genetic effect 1 (predicted resistance from gene expression)	var1	NA	NA
Starting population variance for genetic effect 2 (predicted resistance from challenge test data or growth rate)	var2	25	0.0001756
Starting population variance for environment effect on phenotype 1 (predicted resistance from gene expression)	varenv1	NA	NA
Starting population variance for environment effect on phenotype 2 (predicted resistance from challenge test data or growth rate)	varenv2	225	0.00041
Starting population mean for genetic effect 1 (predicted resistance from gene expression)	smv1	NA	NA
Starting population mean for genetic effect 2 (predicted resistance from challenge test data or growth rate)	smv2	25	0.12
Starting population mean for environment effect 1 (on predicted resistance from gene expression)	smv1env	NA	
Starting population mean for environment effect 2 (on predicted resistance from challenge test data or growth rate)	smv2env	25	0
Quantile not to be selected for phenotype 1 ie.GE , or for phenotype 2 when it is used for direct selection like GE or for trait like growth rate (ie. 0.95 means that 5% best individuals or best families are selected based on GE results or on growth rate)	quanphe1	See scenarios compared in report	See scenarios compared in report
Quantile not to be selected for phenotype 2 WITH EBV ie.CT WITH EBV (ie. 0.90 means that 10% best EBV families are selected)	quanphe2	See scenarios compared in report	See scenarios compared in report
%improvement made in feed conversion ratio with every % improvement in growth rate (ie. A ratio that can be used to estimate fcrg for each generation of selective breeding)	impfcr	0.18	
Correlation between survival of abalone in challenge and field tests	r_s	0.95	
Costs associated with no-tagging (ie. DNA pedigreeing of pooled families)			
Cost of DNA pedigreeing per animal			
Variation in contribution to subsequent generations Ie. Representation of best families after grow-out if animals are randomly picked for DNA pedigreeeing, and number of individuals that must be genotyped in order to give required proportion selected. Cost of temporary tag.			
a/average number of animals per family surviving through to slaughter			
b/variance in number of animals per family surviving through to slaughter			
c/cost of temporary tag.			
total number of animals tested (genetic pedigree test)	ngt	0	determined by a & b (above) and depends on famnum and quanphe 1 & 2 (next sheet)
cost of each genetic test (eg. each microsatellite test)	$cost_{gpt}$	10	
estimate of the number of genetic tests required (genetic pedigree test)	n_{gptr}	5	

16. Appendix 5. Additional pricing scenarios tested using the model for the selective breeding program

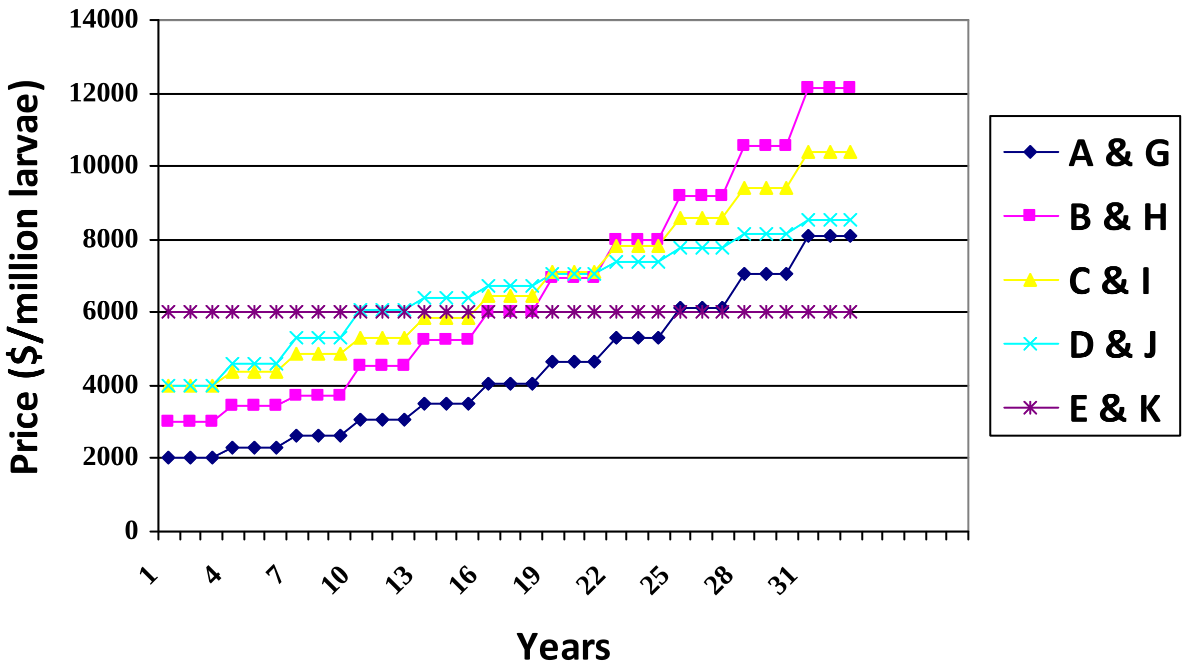
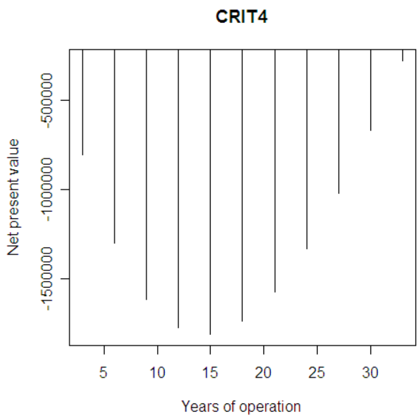
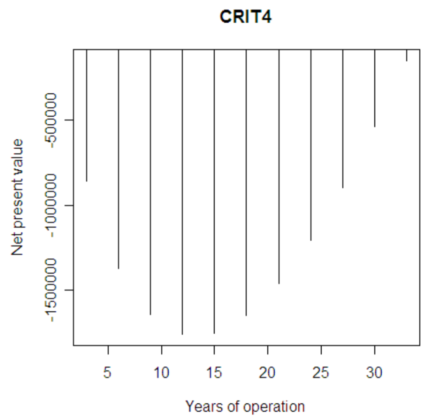


Figure 11. Pricing scenarios considered for calculation of net present value (Figure 12 A-E and G-K below). A and G, starting price of $2000/million larvae, increasing by 15% each generation (stepping up in price once every 3 years with release of the new generation of improved stock). B and H, starting price of $3000/million larvae, increasing by 15% each generation (stepping up in price once every 3 years with release of the new generation of improved stock). C and I, starting price of $4000/million larvae, increasing by 10% each generation (stepping up in price once every 3 years with release of the new generation of improved stock). D and J, starting price of $4000/million larvae, increasing by 15% for 3 generations each generation and 5% per generation after generation 3 (stepping up in price once every 3 years with release of the new generation of improved stock). E and K, starting price of $6000/million larvae, remaining at this price over time.

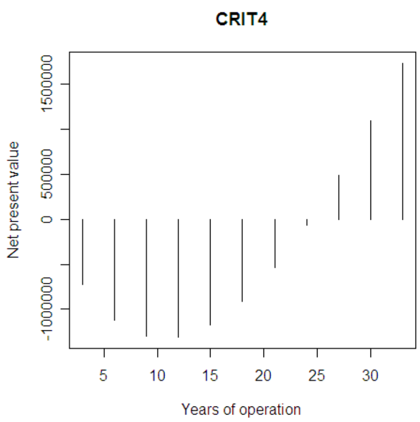
A


CRIT4
Net present value
-500000
-1000000
-1500000
5 10 15 20 25 30
Years of operation

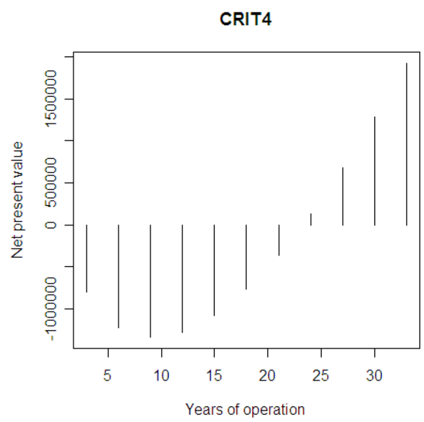
G


CRIT4
Net present value
-500000
-1000000
-1500000
5 10 15 20 25 30
Years of operation

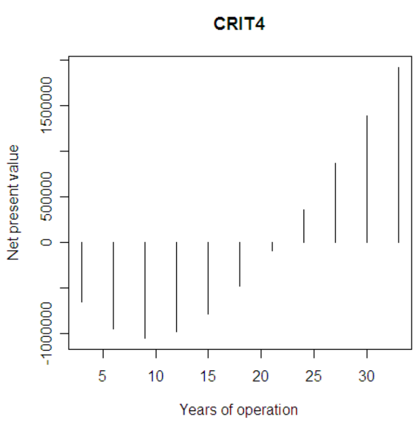
B


CRIT4
Net present value
1500000
500000
0
-1000000
5 10 15 20 25 30
Years of operation

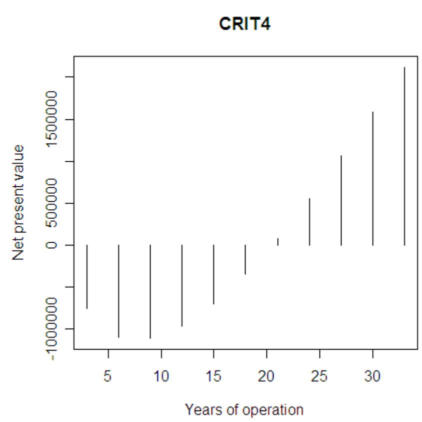
H


CRIT4
Net present value
1500000
500000
0
-1000000
5 10 15 20 25 30
Years of operation

C


CRIT4
Net present value
1500000
500000
0
-1000000
5 10 15 20 25 30
Years of operation

I


CRIT4
Net present value
1500000
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5 10 15 20 25 30
Years of operation

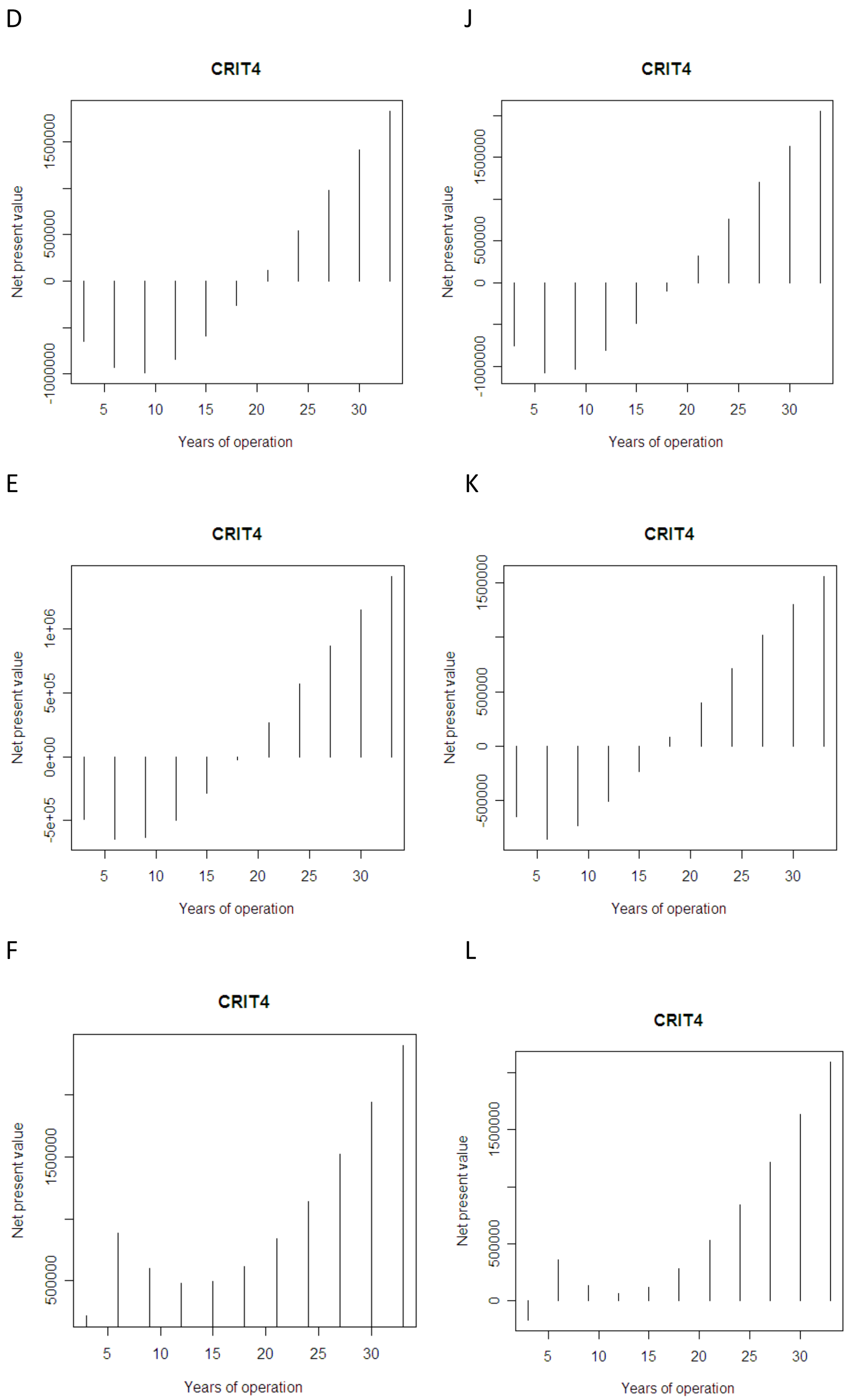

Figure 12. Net present value predicted over 30 years of operation for a selective breeding program producing 100 families of blacklip and 100 families of greenlip abalone each generation. A-F assume high uptake of 75% for unimproved stock when the selective breeding program begins, with a slow growth in uptake up until 95% after genetic improvement is made and demonstrated. G-L assumes low uptake of 50% for unimproved stock when the selective breeding program begins and a rapid increase in uptake to 95% after 2 generations of selective

breeding (6 years) after genetic improvement is made and demonstrated. Six different pricing scenarios were considered (see Figure 11 above for a description of each scenaro).

17. Appendix 6. Economic impact. Comparison of the three scenarios for running the selective breeding program and basic cost breakdown

Table 8. Economic outcome after 10 generations of selection using 33 families.

Profitability PA with 10 generations of selection	Disease CRIT1-Family breeding value	Disease CRIT2-Prediction of challenge test phenotype using gene expression profile	Disease CRIT3-Combination of CRIT1 and CRIT2	Growth Rate Trait CRIT4
Cost	$ 345,614	$ 834,072	$ 741,667	$ 340,072
Relative percent survival	30	12	65	NA
Opportunity cost	$ 5,707,607	$ 2,295,177	$ 12,448,777	$ 39,262,482
Savings from reduction in compensation fish	$ 1,756,800	$ 1,126,760	$ 3,001,427	NA
Savings in labour costs due to reduced removal and disposal of dead fish	$ 4,557	$ 1,832	$ 9,939	$ 7,688,942
Benefit to cost ratio	22:1	4:1	21:1	138:1
Total added benefit per kg of fish produced	$ 2.07	$ 0.95	$ 4.28	$ 13.01
Nominal economic effect on operating income	$ 7,123,349	$ 2,589,698	$ 14,718,476	$ 46,611,351

Table 9. Economic outcome after 10 generations of selection using 100 families.

Profitability PA with 10 generations of selection	Disease CRIT1-Family breeding value	Disease CRIT2-Prediction of challenge test phenotype using gene expression profile	Disease CRIT3-Combination of CRIT1 and CRIT2	Growth Rate Trait CRIT4
Cost	$ 335,080	$ 828,472	$ 735,134	$ 328,806
Relative percent survival	53	-1	87	NA
Opportunity cost	$ 10,149,865	$ -185,742	$ 16,484,008	$ 56,536,707
Savings from reduction in compensation fish	$ 2,576,977	$ 668,706	$ 3,746,455	NA
Savings in labour costs due to reduced removal and disposal of dead fish	$ 8,104	$ -148	$ 13,161	$ 9,784,691
Benefit to cost ratio	38:1	1:1	28:1	202:1
Total added benefit per kg of fish produced	$ 3.53	$ 0.13	$ 5.61	$ 18.37
Nominal economic effect on operating income	$ 12,399,865	$ -345,656	$ 19,508,490	$ 65,992,592

Table 10. Economic outcome after 10 generations of selection using 150 families.

Profitability PA with 10 generations of selection	Disease CRIT1- Family breeding value	Disease CRIT2- Prediction of challenge test phenotype using gene expression profile	Disease CRIT3- Combination of CRIT1 and CRIT2	Growth Rate Trait CRIT4
Cost	$ 355,717	$ 1,095,805	$ 955,797	$ 346,138
Relative percent survival	59	45	90	NA
Opportunity cost	$ 11,317,187	$ 8,499,096	$ 17,198,752	$ 70,815,489
Savings from reduction in compensation fish	$ 2,792,501	$ 2,272,194	$ 3,878,418	NA
Savings in labour costs due to reduced removal and disposal of dead fish	$ 9,036	$ 6,786	$ 13,732	$ 11,181,771
Benefit to cost ratio	40:1	10:1	22:1	237:1
Total added benefit per kg of fish produced	$ 3.91	$ 2.99	$ 5.84	$ 22.71
Nominal economic effect on operating income	$ 13,763,006	$ 9,682,271	$ 20,135,105	$ 81,651,122

Table 11. Average costs per year calculated for running a selective breeding program with 100 families under the 4 different selection criteria.

	Basic costs			
Feed for growout (average year)	$ 4,125.00			
Power growout (average year)	$ 2,240.00			
Labour growout (average year)	$ 3,200.00			
Other overheads growout (average year)	$ -		s	
Feed for spat (average year)	$ 33.33			
Power spat (average year)	$ 2,000.00			
Labour spat (average year)	$ 10,666.67			
Other overheads spat (average year)	$ -			
Power for hatchery (average year)	$ 133.33			
Labour hatchery (average year)	$ 8,000.00			
Other overheads hatchery (average year)	$ -			
Cost of tags (average year)	$ 666.67			
Labour tagging (average year)	$ 9,000.00			
Distribution of larvae for growout	$ 1,400.00			
Cost manager and staff to keep SBP running (in addition to labour costs above)	$ 160,934.00			
Accounting fees	$ 5,000.00			
Facility lease cost	$ 60,000.00			
Permits	$ 1,000.00			
Any additional costs due to SBP	$ 30,000.00			
TOTAL BASE COSTS =	**$ 298,399.00**			
	Disease CRIT1- Family breeding value from challenge testing	**Disease CRIT2- Prediction of challenge test phenotype using gene expression profile**	**Disease CRIT3- Combination of CRIT1 and CRIT2**	**Growth Rate Trait CRIT4**
Additional costs dependant on selection criteria	$ 36,681.33	$ 530,073.33	$ 436,734.67	$ 30,406.67
GRAND TOTAL..... basic and additional costs	**$ 335,080.33**	**$ 828,472.33**	**$ 735,133.67**	**$ 328,805.67**

18. Appendix 7. Draft business proposal for a selective breeding program to service mainland abalone farms.

Nick Robinson (nick.robinson@nofima.no)

Purpose

This proposal is to create a stand-alone abalone selective breeding entity ("High Performance Abalone or HPabalone", a Pty Ltd company) which will service a significant proportion of the industry in Australia. The venture will be financed by the Abalone farmers (shareholders) with support from appropriate commonwealth and state government grants.

Introduction

The establishment of a centralised, well designed selective breeding program has proven a key to the successful development and ongoing viability of major aquaculture industries worldwide. Major world aquaculture species, (eg. Atlantic salmon, rainbow trout, carp, white shrimp, catfish, tilapia and oysters) are typically serviced by two or three such programs. The first such major breeding program was established for Atlantic salmon in Norway by Nofima (formerly Akvaforsk), and the impact of this program has been well documented. Almost the entire production in Norway, and much of the production in Chile, is from fish derived from this program (eg. sold by Aquagen). Thodesen et al. (1999) compared the performance of unselected animals to selectively bred Atlantic salmon grown under the same conditions after 5 generations of selection on growth rate. The growth rate of the selectively bred fish was more than doubled (+113%), feed consumption increased by less than 50%, protein retention was 9% improved, energy retention was 14% improved and the feed conversion ratio (feed to gain) was 20% improved. After 7 generations this improvement in feed conversion ratio alone resulted in a saving of $300 million in feed costs each year to the US$ 1-2 billion export industry in Norway.

Typically, in a well designed program, a genetic change of 10-15% per generation can be achieved for a trait like growth rate, and the selective breeding program can yield a benefit-cost ratio of around 15:1 per generation of selection (Gjedrem, 2000). For abalone, Robinson & Li (2008) have predicted similar genetic change and benefit-cost ratios (Figures 1 and 2). With an initial adoption rate of 50% growing to 95%, and production growing at 100 tonne per year to 3,800 tonne, after 10 generations of selective breeding to improve growth rate Robinson & Li (2008) predict a benefit-cost ratio of 200:1, total added benefit per kg of production of $18.23 and nominal economic effect on operating income of $65 million for the abalone industry in Australia.

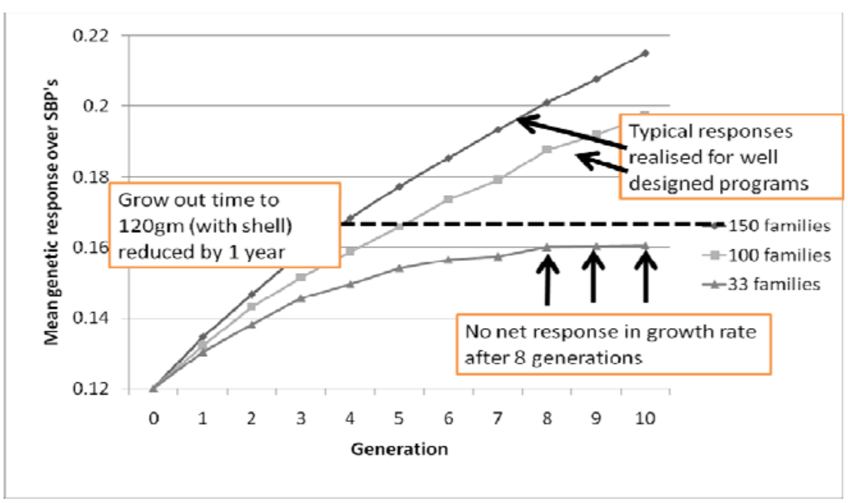

Figure 1. Mean genetic response predicted after correcting for the effect of inbreeding depression on growth rate (harvest weight in kg after a fixed 3 year farming period). The response is shown over 10 generations of selective breeding for breeding programs utilising 33 families, 100 families or 150 families.

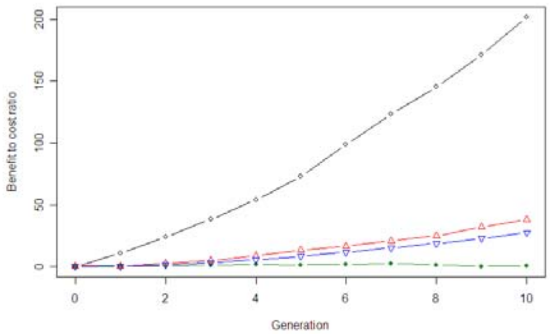

Figure 2. Benefit-cost ratio predicted over 10 generations of selective breeding using different selection criteria. The black line plotted with open black diamond's shows selection for growth rate.

Existing selective breeding programs starting for abalone (on-farm programs in SA, VIC and Tasmania) will provide limited benefit due to small family numbers, little genetic expertise and/or exclusivity. For example, a program based on 33 families, or a poorly designed program, could result in a negative genetic response (eg. reduced growth rate and greater disease susceptibility) after a few generations of selection (Robinson, Li, 2008).

Proposal/benefits

This proposal is to create a stand-alone abalone selective breeding entity ("High Performance Abalone or HPabalone", a Pty Ltd company) which will service a significant proportion of the industry in Australia. There will be incentives for the stand-alone company to improve its performance (ie. to increase the rate of genetic improvement and expand its market base) and thereby benefit its major shareholders.

Base commitment to the company by the abalone industry

- Donation of favourite broodstock to the starting population
- Seed capital (ie. purchase of primary shares in the company)
- Secondary shares (according to millions of larvae purchased)

Returns to industry shareholders

- Competitive advantages and total added benefit to participating farms growing "High Performance Abalone" (HPabalone)
- Discounted price for larvae

Growth of company revenue achieved by

- Stimulating higher production levels, reduced feed costs/kg of production and demand among users
- External domestic sales (more Australian farms joining and buying from the program)
- Sales of excess family material for processing

Once established the company will explore opportunities for export sales of HPabalone. Opportunities for expense offsets (eg. government grants) will be explored and actively sought by the company.

The cost of investment and entitlement to larvae will depend on the number (tonnage) of participating farms (ie. a sliding scale of investment costs). A conservative case study is shown in detail below and an indicative sliding scale of the net cash outlay per million larvae is shown in Table 1.

Assumptions

- The company supplies "High Performance" greenlip, blacklip and hybrid abalone larvae.
- The facility used maintains a high level of biosecurity, disease surveillance and testing.

- Improved growth rate is the major trait of focus. Improvement of other key traits will also be investigated and incorporated into the breeding objectives of the company.
- The company selects from around 100 families of each species every generation in order to achieve a strong genetic response and while limiting inbreeding depression and reduction of genetic variance.
- Families are grown out and measured by the selective breeding company. Some tagged animals are grown out and tested among commercial production stock by customers (this provides data for selection, opportunities to assess genotype-by-environment interactions and backup in case of disaster).
- Larvae for sale are tailored to meet customers' preferences for species, colour and patterning and represent the "best of the best" families created that year. Fifty larvae are sold to seed every kg of production.
- The selective breeding company can provide confidential feedback to each customer on how animals perform on that farm relative to the average for the industry (a benchmarking opportunity).
- All excess family stock can be sold for processing by the selective breeding company

Conditions

- Ratification by an industry member of the cost/case (assuming operating costs of approximately $350K per annum and capital supplied under a lease arrangement) that was developed using primary figures from Mark Gervis.
- Ratification of the business model for the entity by an independent financial auditor.
- Commitment by a sufficient proportion of the industry to becoming founding investors and commitment to the purchase of seed from the company.
- Notional approval by state government authorities for translocation from the selective breeding programs facility to farms in Victoria and South Australia at least.
- Growth of the company dependant on internal domestic sales, external domestic sales, sale of excess family material for processing (mature stock) and the potential for export sales (explored once the company is established and supplying domestic markets).
- Potential expense offsets such as commonwealth and state grants and reduced facility lease costs giving equity into the company.
- A suitable facility for lease by the company can be found.
- Undertake trials to ensure larvae can be transported over long distances.

Risks and mitigation

- *High start up costs for participating farmers and lack of confidence in the managerial capability may dissuade investment*. An existing corporate entity could provide a leadership role, offering financial and business advice. Ausab Pty Ltd, which manages the export of about 65% of Australia's farmed Abalone production, and has a vested interest in increased production and improved quality, could be an ideal candidate.
- *High Aus$ continues or value of abalone product slumps*. As genetic improvement is made the stock that is grown by the industry will become more resilient to this risk.
- *Primary industries rules prevent translocation of improved seed to sea based facilities or restrict sea based farms to locally sourced varieties.* Produce infertile stock for growout. Research needed into genetic and other methods. Demonstrate strict biosecurity and quarantine measures.

- *Translocation between mainland states is restricted by primary industries.* Demonstrate strict biosecurity and quarantine measures.
- *Bad press stemming from competition (eg. abalone divers association).* Produce infertile stock for growout. Research needed into genetic and other methods. Demonstrate strict biosecurity and quarantine measures.
- *Contamination from pollution, algal blooms or disease*. Contingency for total recirculation. Stock tested on farm can be retrieved in emergency.
- *Loss of key hatchery management staff or quantitative geneticists.* Provide good working environment (peers, location etc).
- *Global warming*. Breed for high temperature tolerance.
- *Competitors arise (in Aus).* Stay ahead (optimised methods, research, protection).
- *Survival of larvae is affected after several hours of transport.* Trial time and conditions, larval stage, vehicle (temp vibrn etc) to optimise.

Potential Cost Offsets

As the company will involve a number of farms, and as the benefits from the company's activities will be large and realised by a significant proportion of the industry, the company running the selective breeding program will be well positioned to attract commonwealth and/or state startup and research grants. Some possibilities are listed below.

Possible grants and concessions that may be applicable (some uncertainty exists over the status and level of assistance provided by some of these programs with the start of the new Commonwealth Government)

Seafood Industry Development Fund
New industries development program
Industry cooperative innovation program
Cooperative Research Centres Program
R&D Tax Concession
Pooled Development Fund
Commercial ready program
Commercialising emerging technologies
Fisheries Research & Development Corporation
International Science Linkages
Small Business Entrepreneurship Program

Another potential expense offset might be through an equity arrangement which reduces lease costs.

Summary

- Under case study, founding shareholders are entitled to ≈1 million larvae for every $21,000 worth of shares
- The net cash outlay on larvae by founding investors is more than halved after 10 years (due to discounts)
- A 100 tonne farm, investing $100K per year should gain around $1.3 million in total added benefit for the investment by year 9
- Benefits steadily increase with each new generation of selected stock
- Benefits are higher and costs are lower than might be achieved by individual farms running their own selective breeding program in isolation

Case study

Five mainland farms, representing a total 250 tonne current production (around 1/3 of current Australian production), commit to investment/supply from HPabalone. No external domestic sales occur. No cost offsets (Government grants). Production by the Australian industry grows from the current 800 tonne level by 100 tonne per year. Excess abalone families are sold at $30 per kg.

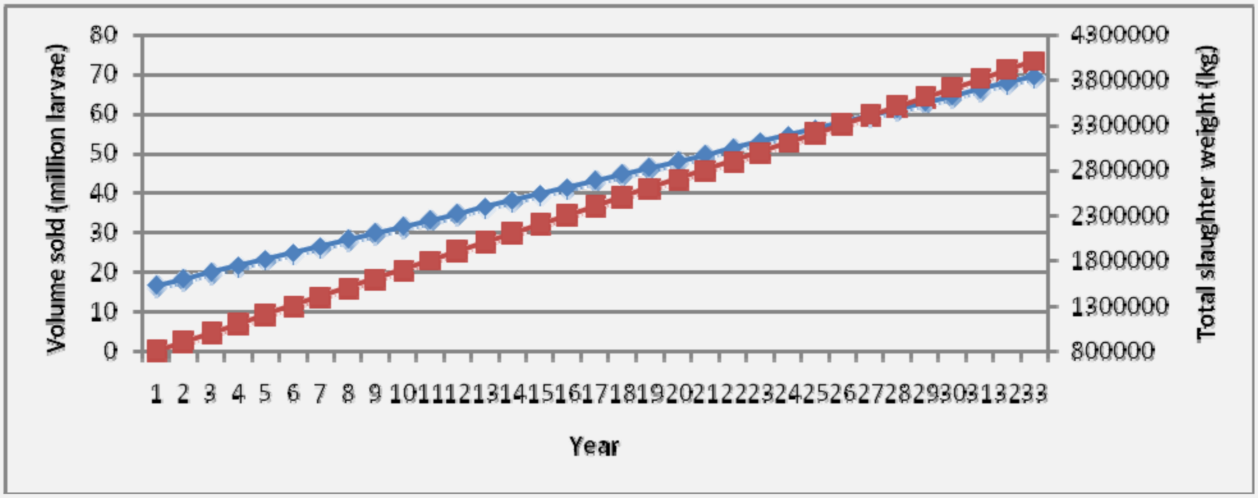

Figure 3. Volume sold (million larvae, blue line) for selective breeding program assuming investment by one-third of the Australian industry. Growth in volume is due to projections for growth of participating farms (assumed from overall growth projected for industry of 100 tonne per annum, red line).

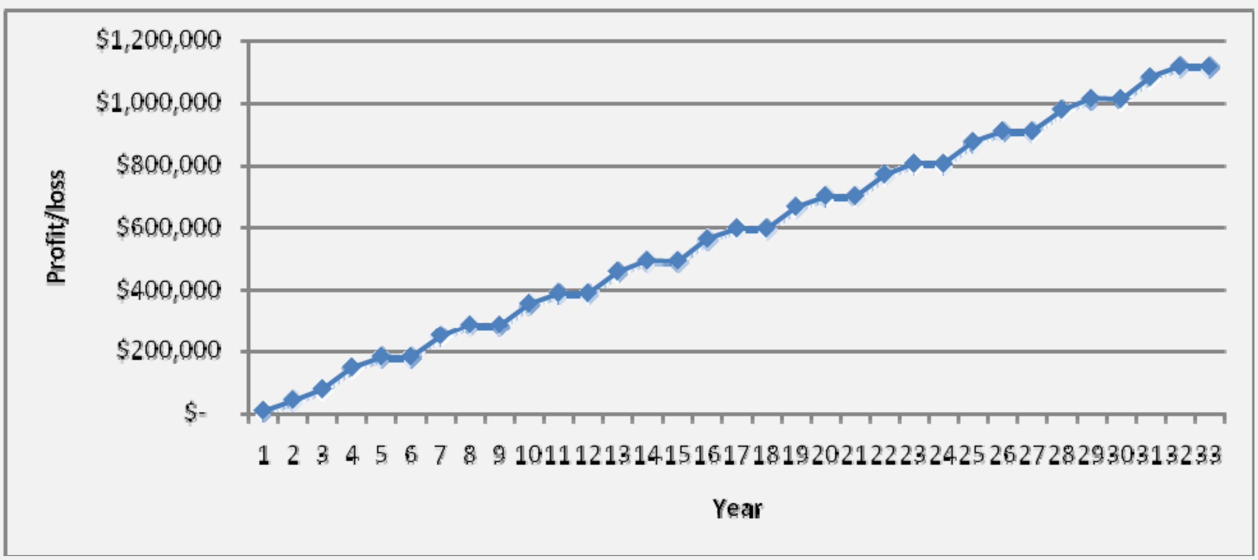

Figure 4. Profit/loss projections for selective breeding program assuming investment by one-third of the Australian industry.

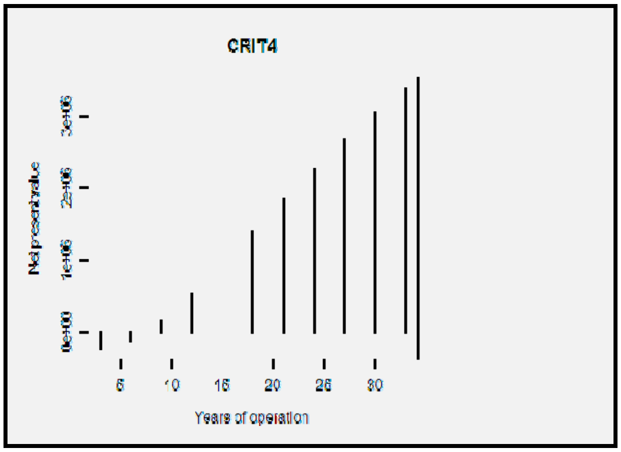

Figure 5. Net present value predicted over 30 years of operation for a selective breeding program producing 100 families of blacklip and 100 families of greenlip abalone each generation assuming investment by one-third of the Australian industry and assuming pre-startup (scoping) costs of $100K.

The following projections are for a participating farm with a constant production of 100 tonne per year.

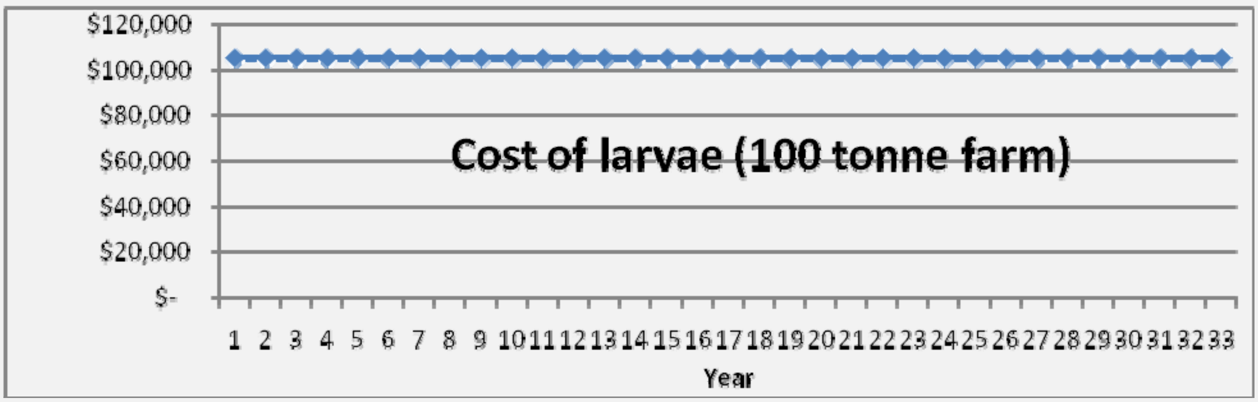

Figure 6. Cost of larvae purchase from the selective breeding program for a 100 tonne farm assuming investment by one-third of the Australian industry. Does not account for discounts received or total added benefit from growing abalone.

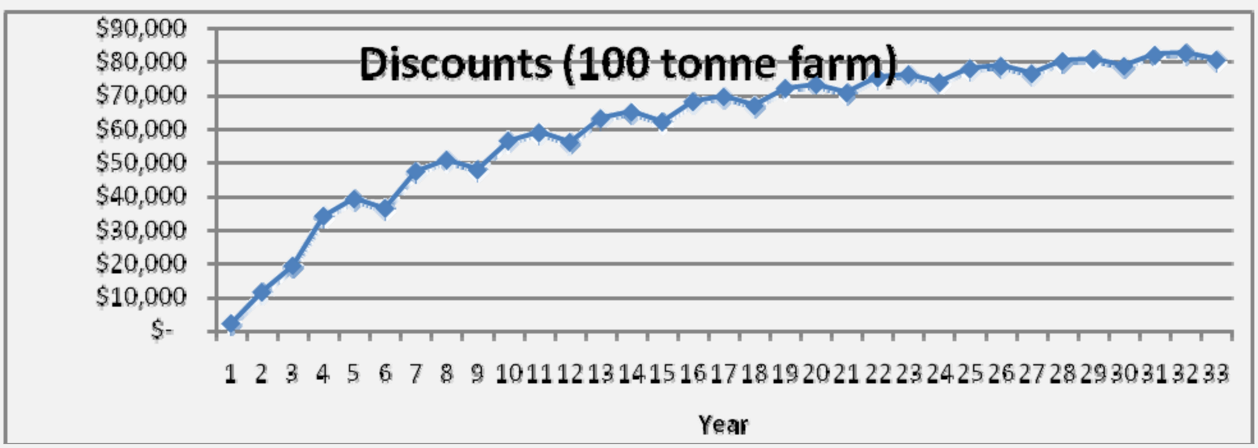

Figure 7. Discounts received for a 100 tonne farm growing larvae sourced from the selective breeding program assuming investment by one-third of the Australian industry.

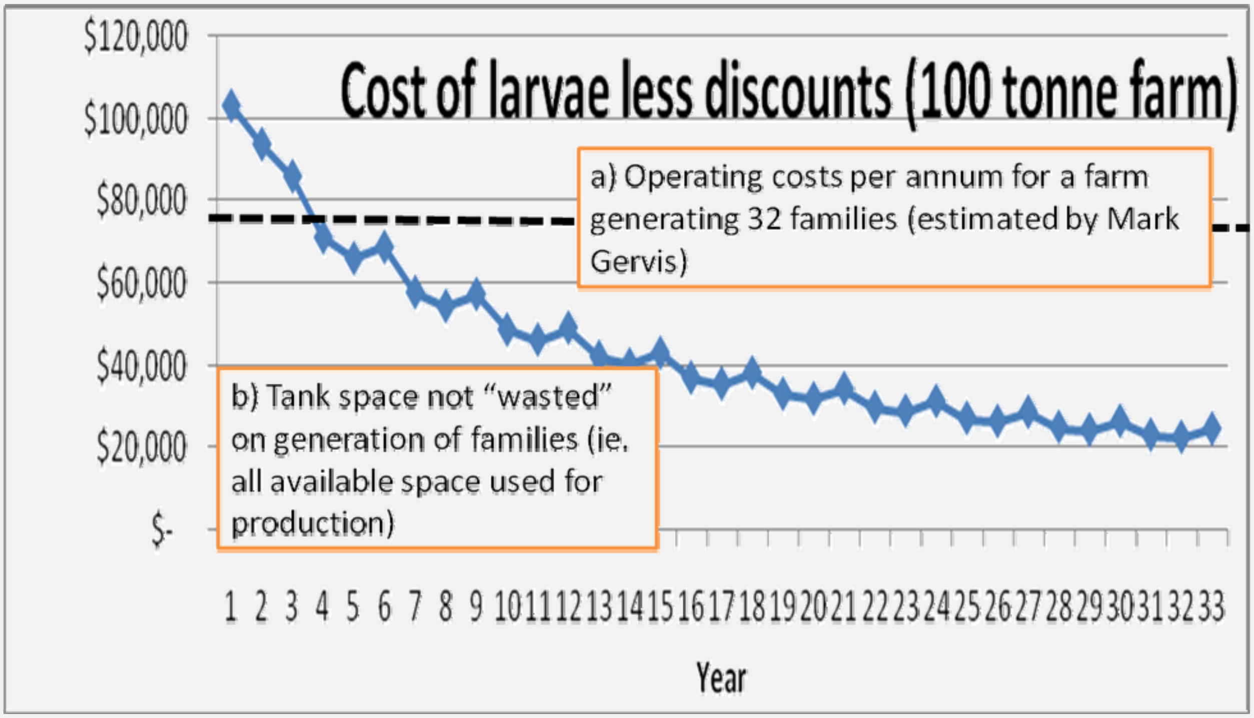

Figure 8. Net cash outlay (cost of larvae less discounts received) for a 100 tonne farm growing larvae sourced from the selective breeding program assuming investment by one-third of the Australian industry. Dashed line shows Mark Gervis's estimate of the operating costs per annum for a farm generating 32 families.

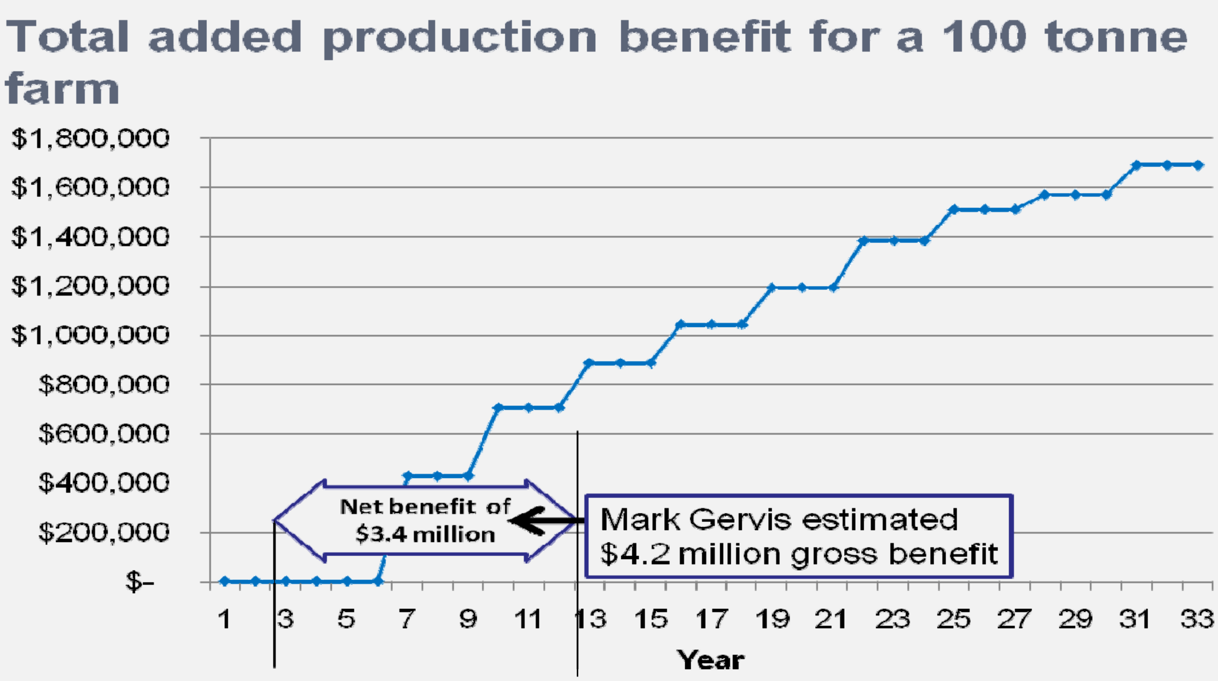

Figure 9. Total added benefit to production for a 100 tonne farm growing larvae sourced from the selective breeding program.

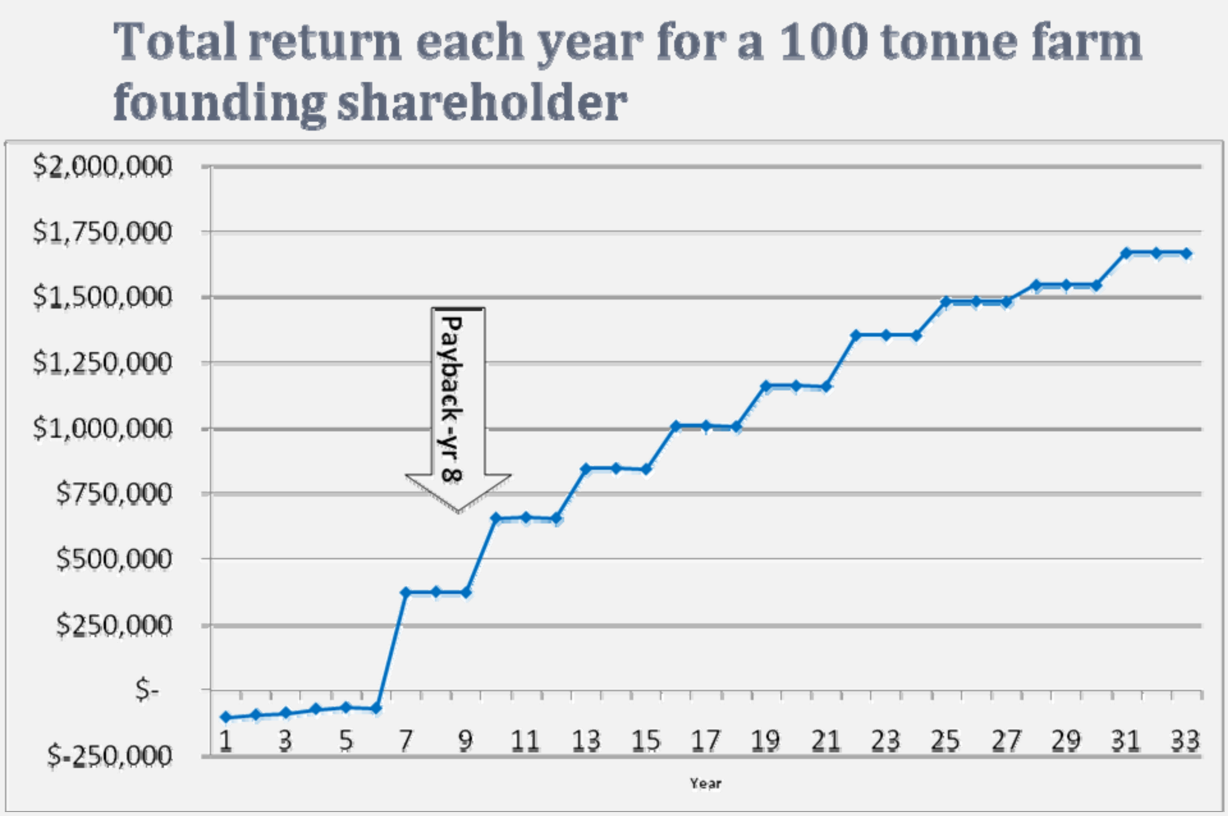

Figure 10. Total return each year for a 100 tonne farm growing larvae sourced from the selective breeding program assuming investment by one-third of the Australian industry.

These are conservative projections which assume that growth of the revenue stream is due solely to projected growth in the level of production of those five mainland farms who commit. **That is, the projections <u>exclude</u> potential offset of expenses from government grants, growth in revenue stream due to stimulation of higher production levels and demand among users, more Australian farms joining and buying from the program and/or export sales.** The projections also exclude additional benefits that can be gained by the industry with careful choice of larvae used for distribution (ie calculations are based on the average level of genetic improvement across the 100 families). Benefits can be supplemented by choosing the "best-of-the-best" families for distribution.

The price per million larvae has been calculated to cover the startup costs of the company. Original shareholders will be advantaged by receiving discounts, which essentially reduce the cost per million larvae for these shareholders. The discount projection is based on growing profit margins. As participating farms grow their production, a greater volume of larvae will be sold by the selective breeding company. Sales of excess family stock after year 3 will also contribute to the profit and discounts paid.

Table1. Indicative sliding scale of investment costs showing dependency on number of founding investors and larval requirements. The net cash outlay per million larvae will be reduced over time as the industry grows.

Net cash		Proportion of industry production

			represented by founding investors			
			25%	**33%**	**50%**	**75%**
outlay (cost of larvae less discounts received)	per million larvae (assume 50 larvae are sold to seed every kg of production)	Year 1	$28,000	$21,000	$15,000	$9,500
		Year 10	$12,800	$9,700	$6,400	$4,300
	per 100 tonne farm (per annum)	Year 1	$136,000	$103,000	$68,000	$45,000
		Year 10	$64,000	$49,000	$32,000	$21,000

References

Anonymous, 2007. Victorian abalone aquaculture translocation protocol, Fisheries management report series. The State Goernment of Victoria, Department of Primary Industries, Fisheries Victoria, Melbourne, pp. 1-31.

Bondad-Reantaso, M.G., F., B., 2005. Molluscan pathogens of concern in ASEAN. In: NACA (Ed.), The way forward: Building capacity to combat impacts of aquatic alien species and associated transboundary pathogens in ASEAN countries. Network of aquaculture centres in Asia-Pacific, pp. 179-195.

Elston, R.A., Cheney, D.P., 2004. Shellfish high health program - Building success through health management and disease prevention. World Aquaculture 35, 48-52.

Falconer, D.S., Mackay, T.F.C., 1996. An introduction to quantitative genetics. Addison Wesley Longman Limited, Edinburgh Gate, 464 pp.

Gavine, F.M., Ingram, B.A., Hardy-Smith, P., Doroudi, M., 2007. Biosecurity control measures for abalone viral ganglioneuritis: A code of practice. Fisheries Research and Development Corporation and The State of Victoria, Department of Primary Industries, Alexandra, pp. 1-31.

Gjedrem, T., 2000. Genetic improvement of cold-water fish species. Aquac. Res. 31, 25-33.

Gjerde, B., Gunnes, K., Gjedrem, T., 1983. Effect of inbreeding on survival and growth in rainbow trout. Aquaculture 34, 327-332.

Ingram, B.A., Gavine, F.M., Lawson, P., 2005. Fish health management guidelines for farmed murray cod., Fisheries Victoria Research Report Series No 32. The State of Victoria, Department of Primary Industries, Alexandra.

Robinson, N., Li, X., 2008. Scope and economic analysis of options for a nationally unified breeding program that provides significant economic benefit to the Australian abalone industry., Final report to the Australian Seafood CRC, Project No. 2008/722. . South Australian Research and Development Institute., Adelaide.

Robinson, N.A., Hayes, B.J., 2008. Modelling the use of gene expression profiles with selective breeding for improved disease resistance in Atlantic salmon (Salmo salar). Aquaculture 285, 38-46.

Rye, M., Mao, l.L., 1998. Nonadditive genetic effects and inbreeding depression for body weight in Atlantic salmon (Salmo salar L.). Livest. Prod. Sci. 57, 15-22.

Thodesen, J., Grisdale-Helland, B., Helland, S.J., Gjerde, B., 1999. Feed intake, growth and feed utilization of offspring from wild and selected Atlantic salmon (Salmo salar). Aquaculture. Nov 180, 237-246.