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Genetic improvement and effective dissemination: Keys to prosperous and sustainable aquaculture industries

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Abstract

There is an increasing demand for fish in the world due to a growing population, better economic situation in some sectors, and greater awareness of health issues in relation to food. Since capture fisheries have stagnated, fish farming has become a very fast growing food production system. In this presentation, the author gives an overview of the technologies that are available for genetic improvement of fish, and briefly discuss their merit in the context of a sustainable development. He also discusses the essential pre-requisites for effective dissemination of improved stock to farmers. It is concluded that genetic improvement programs based on selective breeding can substantially contribute to sustainable fish production systems. Furthermore, if such genetic improvement programs are followed up with effective dissemination strategies, they can result in a positive impact on farmers' incomes.

Introduction

Production systems in developing countries are largely based on the use of unimproved species and strains. As knowledge and experience are accumulated in the management, feeding and animal health issues of such production systems, the availability of genetically more productive stock becomes imperative in order to use the resources more effectively. For instance, there is little point in providing ideal water conditions and optimum feed quality to fish that do not have the potential to grow faster and to be harvested in time to provide a product of the desired quality. Refinements in the production system and improvement of the stock used must progress hand in hand.

In terrestrial animal species (e.g. dairy cattle, pigs, poultry), genetic improvement programs have made a substantial contribution to industry productivity and viability. The gains achieved among plants species have been even more spectacular. There appears to be great potential for improvement in aquatic animal species because comparatively little application of genetic improvement technology has taken place to date. Hence, there is ample justification for the planning, design and implementation of research, development and technology transfer of genetic improvement programs for aquatic species.

Such programs are particularly well suited to contribute to the fulfillment of noble aims, such as increasing the amount of animal protein available to a greater number of the population of developing countries, thus assisting in achieving greater food security. Furthermore, they can do so in a sustainable manner, and without having undesirable environmental repercussions. In this paper, the author gives an overview of the technologies that are available for genetic improvement of fish, and also discusses the essential pre-requisites for effective dissemination of improved stock to farmers.

Background against which genetic improvement programs operate

Three factors have resulted in a greater demand for fish in the world; namely, an ever-increasing human population, improved economic situation in some sectors, and greater awareness of the health aspects of food. Since capture fisheries have stagnated, fish farming has become a burgeoning food production system.

Fish genetic improvement as a means to help achieve sustainable gains

Genetic improvement programs have the following highly desirable attributes:

1. The power to modify the animal to suit a purpose or environment
2. The ability to provide greater food security and poverty alleviation by increasing productivity, reliability and consistency, and probably achieving permanent gain

3. The probability to offer solutions to existing or emerging pathogens, and to environmental challenges
4. The potential to provide a favorable return on investment
5. The capacity to fill the gap between demand and supply without a negative environmental impact
6. The opportunity to assist in managing inbreeding in the production system

Genetic improvement programs for fish can contribute to the production system's output, both in quantitative and qualitative terms, by enhancing traits of major importance, such as:

- Growth rate to harvest weight or time
- Survival
- Stress and disease resistance
- Cold water tolerance
- Sexual maturation
- Product quality
- Feed efficiency

The emphasis placed upon these traits will depend on a number of factors. For instance, the phase of the improvement program, specific circumstances in terms of diseases and environmental challenges, and so on. Typically, a considerable amount of effort is devoted to the improvement of growth rate. This is justified because there are clear advantages in producing larger fish in a given period of time, or fish of a particular size in a shorter grow-out period.

The question then is: how can we improve these traits?

Steps in the design of a genetic improvement program

The WorldFish Center is attempting to approach work in this area in a logical and systematic manner by addressing, as deemed appropriate in each circumstance, all the activities that the planning, design and conduct of a genetic improvement program entail, namely:

1. Description or development of the production system(s)
2. Choice of the species, strains and breeding systems
3 Formulation of the breeding objective
4. Development of selection criteria
5. Design of a system of genetic evaluation
6. Selection of brood stock and mating systems
7. Design of a system for the expansion and dissemination of the improved stock
8. Monitoring and comparison of alternative programs

Generally, these steps would be taken in the above order, though not always necessarily. There will always be iterations, going back to earlier steps, making modifications, and rectifying courses of action. Attention to all aspects is essential for the conduct and implementation of an effective genetic improvement program. An example of the use of the approach suggested in this paper may be found in Ponzoni (1992), which also provides references on the methodology that may be used. Each one of the above listed steps is briefly treated, with special reference to the improvement of aquatic animal species.

Brief treatment of each step

Description of the production system(s)

Before even thinking about genetic improvement, fisheries scientists have to be clear about the range of production systems for which genetic improvement is intended. This step entails specifications such as:

(i) Nature of the production system (e.g. mono or poly-culture, smallholder, commercial operation, industrial operation)
(ii) Feeding regime
(iii) Environmental challenge (disease, temperature, water quality)
(iv) Sex and age (or size) of harvested individuals
(v) Social environment

To a large extent, these issues have been addressed in current projects. There could be opportunities, however, in re-examining these range of production systems for which genetic improvement is intended, and, in particular, in anticipating likely developments and possible future production systems.

Identifying major production systems is very important, because there may be no single "genotype" that is "best" in all production environments (i.e. presence of species or strain by environment interaction). If the genotype by environment interactions is suspected (or in fact does exist), treating the expression of the trait(s) in question in different environments as different traits and estimating the genetic correlation between both expressions will be informative.

Choice of the species, strain(s) and breeding systems

The decisions on the choice of species and strain sometimes are partly made for scientists, as when there are limitations on availability of stock, or well-defined local preferences. However, when possible, making the right choice is important because the gain achieved in this way may be equivalent to several generations of selection.

The choice of species and strains should preferably be made on the basis of information derived from well-designed experiments of species and strain comparison, and estimation of phenotypic and genetic parameters (heterosis, heritability, correlations among traits, genotype by environment interactions). Such experiments can be complex and costly, but they are very necessary. The Genetic Improvement of Farmed Tilapia (GIFT) approach used for tilapia (and suggested also for carp) is a sound way of addressing the issue. There could be room for refinements of design in some cases, and in-depth analysis of presently available and future data should be conducted. Greater accuracy in the estimates of phenotypic and genetic parameters can result in greater effectiveness of the genetic improvement programs.

Looking for genes that have a relatively large effect on traits of relevance for the production system(s) by statistical procedures in the data collected could yield valuable results. If any were found, they could become candidates for gene mapping and expression studies.

Formulation of the breeding objective

The formulation of the breeding objective is crucial because it determines "where to go" with the genetic improvement program. The breeding objective is intimately related to the production system. Scientists have to make sure that the trait(s) they improve are those of importance in the actual production system. Generally, these will be the traits that impact upon income or expense in the production system, or those associated with benefits to the user of the improved animals in a non-cash economy, or those that influence sociological preference.

There are two main ways of defining the breeding objective:

(i) As a statement of intent of desired genetic gain in each trait
(ii) From a mathematical function describing the production system, deriving an economic value for each trait

The breeding objective usually includes traits such as: growth rate or size, survival rate, age at sexual maturity, disease resistance, tolerance to water temperature or to other water attributes, flesh quality, and feed conversion. Of these, growth rate (or size at a particular age) has been the most popular, partly because its impact is easily perceived and it can be measured. There are risks, however, in over-simplifying the breeding objective to a single trait, as unfavourable correlated responses can occur. Even if not formally included in the breeding objective, traits perceived as being of importance in the production system should be carefully monitored.

The issue of breeding objectives has been addressed only to a limited extent in some projects. This may be justified by the over-riding importance of size or growth rate. However, there will often be opportunity to refine improvement programs through work on breeding objectives as these evolve. For instance, new traits may have to be formally incorporated as the production system develops, or in response to changing consumer demands. When there is a need for radically different traits, or for very fast improvement beyond what is possible with conventional methods, genetic engineering and the creation of transgenic animals have been proposed as options. However, the costs of implementing such option, and the (often found) lack of acceptability by consumers of the animals thus created, have given rise to considerable controversy, and they should be critically assessed before being proposed as an alternative.

Development of selection criteria

The selection criteria are characters closely related, but not necessarily identical, to the traits in the breeding objective. The breeding objective is about "where to go" with the genetic improvement program, whereas the selection criteria are about "how to get there". The selection criteria are the characters the scientists use in the estimation of breeding values and overall genetic merit of the animals.

Selection criteria may be different from the traits in the breeding objective. For instance, the scientists may be interested in increasing market weight, but they may base their selection on weights taken at an earlier age, before reaching market weight, in an attempt to speed up the selection process by choosing breeding animals earlier. Also, there may be cases in which the scientists do not select directly for the trait in the breeding objective, but use an indicator character instead (e.g. length of fish could be used as an indicator of weight).

The characters used as selection criteria are linked to the traits in the breeding objective via genetic variances and covariances. Hence, the need for phenotypic and genetic parameters in the estimation of breeding values for relevant traits.

There may be new developments through gene mapping and marker assisted selection (MAS). There are some traits that can have importance in the breeding objective but they are difficult to measure. Disease resistance and tolerance to some environmental challenges are two examples. For such traits, "conventional" selection procedures based on quantitative genetics sometimes have limitations, and developments in the area of MAS could be valuable.

Even if scientists concluded that crossbreeding was the best alternative as a breeding strategy, they would still have to consider within breed or strain selection, and the above discussion on selection criteria would be appropriate.

The notion of dealing separately with traits in the breeding objective and characters used as selection criteria can be of help in bringing some of the current and likely future work into sharper focus (e.g. placing MAS in the proper context and perspective in relation to genetic improvement work as a whole).

Design of a genetic evaluation system

With an assumption that the production and breeding system, the breeding objective, and the selection criteria have already been established, the environment for selection should be as close as possible to the production environment, unless there is very clear evidence of absence of genotype by environment interactions.

The genetic evaluation system can vary from something very simple, involving just mass selection for one or a few traits, to something much more complex, involving fitting an animal model to the data, or separating sib, or testing progeny for specific traits (e.g. disease after challenge, flesh quality after slaughter). Depending on their ability to identify individuals and to keep track of pedigrees, scientists may use mass selection, family selection, or, best of all, best linear unbiased prediction (BLUP) breeding values combining the available information. With the very high reproductive rate of fish and the relatively low cost per individual, when deemed necessary, it should be possible to set up families for specific purposes, such as evaluating for disease resistance or for flesh quality.

Individual identification (unique and at an early age) of animals and their parents is one area that is likely to impact upon the genetic evaluation system adopted. Developments in DNA technology (DNA fingerprinting) could be of great assistance. This could be an area worthy of consideration in future research and development proposals.

Selection of brood stock and mating systems

Ideally, scientists would only reproduce the "best" individuals. In practice, they need a compromise between selection intensity and effective population size in order to manage risk (inbreeding). The increase in inbreeding is proportional to 1/2Ne, where Ne is the effective population size. A relatively large Ne is required to:

(i) Sustain long-term genetic variation in the population
(ii) Manage inbreeding
(iii) Increase the selection limit
(iv) Ensure predictable responses to selection

For situations where mass selection is used, Bentsen and Olesen (2002) suggest a minimum of 50 pairs to maintain approximately a 1 per cent increase in inbreeding per generation. With full pedigree information, inbreeding can be managed more effectively, avoiding matings of closely related individuals. When full pedigrees are not an option, sub-dividing the population can help, so that animals can be selected from the various sub-populations.

An aspect that may be worth considering is the establishment of one or more replicates of the selected population for security reasons, in case it was destroyed by disease or some other disaster.

Design of a system for expansion

Genetic improvement typically takes place in a very small fraction of the population. The improvement is achieved in that the "elite" of superior animals is multiplied and disseminated to the production systems. The flow of genes is graphically illustrated in Figure 1.

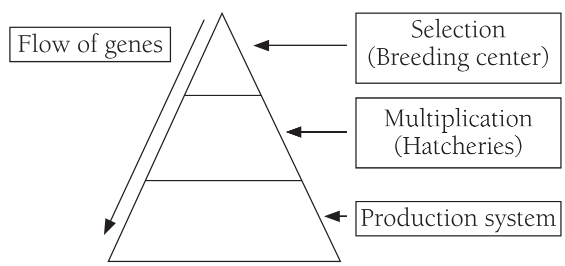

Figure 1. Flow of genes from the breeding Center to the production system.

Fish are very well endowed with their high reproductive efficiency, to develop cost effective structures for the dissemination of genetic gain. The implementation of the genetic improvement program in a relatively small number of animals can be enough to service a very large population involved in production.

Unfortunately, experience shows that when a successful strain is developed and a market for it flourishes, malpractices often proliferate, facilitated by the very high reproductive rate of fish, and stock quality deteriorates as a consequence of inbreeding and small population size. There is no simple way out of this, except perhaps through the creation of a formal structure that is not only technically sound, but also regulates the process and enables the implementation of quality assurance practices. Figure 2 illustrates in a diagrammatic form important considerations that should be made when planning and putting in place a logically based system for the dissemination of improved stock of aquatic species.

There are options, but we have to make considerations about...

❖ **The resources available**
»Staff
»Facilities
»Capital
»Operating location
❖ Competence or access to them
❖ Size and other characteristics of the industry to be serviced
❖ Industry level in terms of technology application and education of members

Options for multiplication

❖ Through Government stations (often limited in their impact)
❖ With participation of private operators
»Joint ventures
»Licensing of hatcheries
»Contracted production
»Sale of breeders to hatcheries with few conditions
»Combinations of the above

Creation of a network of hatcheries

❖ Terms of the agreement
»Financial
»Operational
❖ Training and education of hatchery managers
❖ A brand name for successful marketing
❖ Product standards
»Fingerling size and survival
»Transport and accounting
»Management of inbreeding
»Breeders' age (lag)
»Lag and options for refreshing
❖ Genetic piracy

Figure 2. Considerations to be made during the planning and putting in place of a formal scheme for the dissemination of improved stock from breeding centers to fish farmers.

In designing the system for expansion, the characteristics of the production system have to be taken into consideration again. For instance, if single sex or infertile populations are preferable for production, hormonal treatment in the production system, or chromosome manipulations (e.g. creation of YY males) may be needed in the multiplication phase. The lag created by additional generations before the animals reach the production phase has to be taken into consideration.

The relative sizes of the population sectors involved in selection, multiplication and production should be examined and made consistent with an effective transfer of genetic gain to the production sector.

Monitoring and comparison of alternative programs

Monitoring the genetic improvement program is important to ensure that the anticipated genetic gain is actually achieved. If it is not, action has to be taken to rectify the situation.

Genetic gain can be measured in a number of different ways. The establishment of randomly selected populations is a useful way, particularly when the visual impact created by the comparison of the "selected" vs. "unselected" populations is considered important in increasing the adoption or credibility of results. However, the maintenance of control populations requires funds and effort.

When the visual impact is not a high priority, genetic gain may be estimated using appropriate statistical procedures that rely on the presence of genetic links between generations, instead of establishing control populations,. These genetic links enable the estimation of genetic and environmental trends over time. This is an option that could be explored in current and future projects.

There will often be sensible alternatives in the program steps 1 to 7. Generally, testing all of such alternatives in the field will not be possible, but we could conduct theoretical and numerical work to predict likely outcomes. For instance, we may be interested in assessing te consequences of including or ignoring a particular trait in the breeding objective, or in comparing the merit of a single breeding objective in a range of production systems, or in evaluating particular sources of information as selection criteria in the genetic evaluation of animals. At present, there appears to be no work along these lines, but this is an area worthy of consideration in future planning. Sometimes this type of work helps uncover opportunities to increase the effectiveness of the genetic improvement program, or of saving costs and effort.

What sort of response can selective breeding achieve?

Provided there are: 1) abundant genetic variation in the base population, 2) selection for a well-defined, heritable trait(s), and 3) maintenance of genetic variation by controlling inbreeding and avoiding small population sizes, scientists can then expect genetic gains as shown in Table 1. The gain in growth rate experienced in the case of GIFT fish is shown geographically in Figure 3.

Table 1. Realized responses to selection in growth rate in three species of fish.

Species	Gain per generation %	Number of generations
Atlantic salmon	12.0	6
Nile Tilapia (GIFT)	15.0	5
Rohu carp	17.0	3

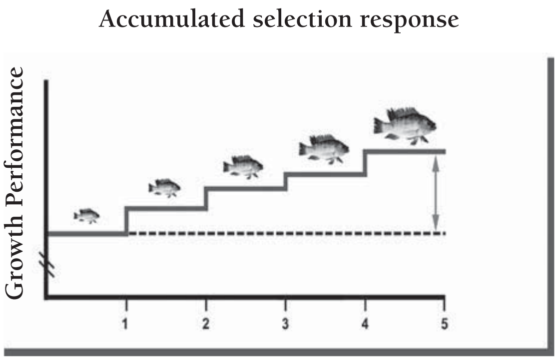

Figure 3. Genetic gain in GIFT fish over five generations.

Concluding remarks

Selective breeding is a genetic technology that can provide continuous improvement of a fish population. Other technologies (e.g. gynogenesis, hybridization, triploids) should not be looked upon as alternatives, but as supplementary to selective breeding. The genetic improvement procedures recommended and implemented by the WorldFish Center utilize naturally occurring genetic variation. In otherwise sustainable aquaculture systems, selective breeding offers great opportunities without undesirable side effects. A number of successful examples exist. Furthermore, if such genetic improvement programs are followed up with effective dissemination strategies, they can result in a highly positive impact on farmers' income.

In the short and medium term, aquaculture genetic improvement programs will be best served by judicious use of proven technology (i.e. based on quantitative genetics), and gradual incorporation of new technologies (e.g. MAS), as evidence on their usefulness becomes available from research, development and validation.

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