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Genetic Improvement of Farmed Aquatic Animals at The WorldFish Center

Prepared by: Raul W. Ponzoni, Nguyen Hong Nguyen, Hooi Ling Khaw, Curtis E. Lind
Fish Breeding and Genetics Group

BACKGROUND

Aquaculture is the fastest growing food production sector in the world today, supplying half of global fish consumption. Production from capture fisheries has stagnated and is unable to meet the anticipated growth in demand. Current indications are that Asian and African aquaculture will need to grow substantially to meet future demand for fish and must do so largely by increasing production per unit of land and water used. In response, WorldFish and partners are placing increasing emphasis on developing technologies that can support national and regional efforts to meet this need.

Together with the lack of affordable and effective feeds, the absence of improved strains capable of producing high quality seed is consistently identified as the most widespread technical obstacle to the development of aquaculture among both smallholders and small- and medium-sized enterprises (SME). In developing countries, very often farmers' strains are not more productive than their wild counterparts (and in some cases they are even less productive) due to poor management of the genetic resource (inbreeding and inadvertent selection in the wrong direction, for smaller fish). To address these issues WorldFish has focused on the development and use of genetically improved strains of fish.

LINKING THE WORLDFISH MISSION TO AQUATIC ANIMAL GENETIC IMPROVEMENT

The mission of The WorldFish Center is to 'reduce poverty and hunger through improved fisheries and aquaculture'. We work with partners to achieve this through relevant research, development and technology transfer, capacity building and policy support. Genetic improvement by selective breeding is an area in which WorldFish has been active and successful. For example, one of the products the Center is especially proud of is an improved strain of tilapia *(Oreochromis niloticus)*. The improved strain is called GIFT, an appealing acronym for Genetically Improved Farmed Tilapia. The strain has achieved a total genetic gain in live weight of at least 64% over nine generations, without any deterioration in survival rate.

WorldFish also contributed to the development of Jayanti rohu *(Labeo rohita)*, an outstanding strain that is now widely used by farmers in India. Furthermore, WorldFish provides advice and support to genetic improvement programs for a number of species in more than a dozen Asian, African and Latin American countries. Improved strains are essential to smallholder farmers and small and medium enterprise (SME) producers. Otherwise, the resources they assign to feeding and to managing the production environment may be wasted. Growth and survival rate are two key traits in making aquaculture economically viable. The value of survival is obvious since dead fish constitute a total loss. When fish of a particular size are desired greater growth rate enables achieving that aim in a shorter period of time, whereas if the duration of the production cycle is fixed, larger fish will be produced. In either case greater growth rate is advantageous. With the passage of time it may become necessary to select for other traits, such as disease resistance and aspects of carcass yield and flesh quality. In some cases the environment may pose challenges that require broadening the breeding objective to include salinity or cold tolerance.

EXTERNAL RECOGNITION

The work conducted by WorldFish on genetic improvement for aquatic farm animals is recognized worldwide. One of the most notable, recent examples of such recognition is the inclusion of the GIFT strain as one of the cases highlighted in the publication 'Millions Fed: proven successes in agricultural development', produced by the International Food Policy Research Institute (IFPRI)[1] . In 2005, the Center was named a Tech Museum Awards Laureate for its development of this popular strain.

ECONOMIC BENEFITS

Genetic improvement typically takes place in a relatively small population, in the order of a few hundred individuals selected per generation. The economic impact of genetic improvement in any such population is small, but it becomes spectacular when it is multiplied through hatcheries, disseminated to

Genetically Improved Farmed Tilapia (GIFT)

farmers, and expressed millions of times in the production system. It is this attribute of genetic improvement by selective breeding that makes it such a unique and powerful technology. Furthermore, genetic gain is permanent and cumulative, that is, the new gain achieved in each generation builds upon gains made in earlier generations. These characteristics (being permanent and cumulative) are unique to genetic improvement and cannot be found in other aquaculture technologies.

WorldFish scientists have shown that investment in genetic improvement programs at a national level can result in very favorable benefit/cost ratios, in the order of 8:1 to 60:1, depending on the specific circumstances, sometimes even greater [2] .

STEPS IN THE PLANNING, DESIGN AND CONDUCT OF A GENETIC IMPROVEMENT PROGRAM

The WorldFish Center has played a pioneering role in the initiation and conduct of genetic improvement programs for aquatic animal species in developing countries. This leading role should continue, given that there is a clear need for such programs, and that the majority of those currently underway are still at a relatively early stage of development. Generally, they have not yet reached a stage of maturity whereby they can be taken over by government agencies or by the private sector in their respective countries. Furthermore, the number

[1] http://www.ifpri.org/publication/millions-fed

[2] Ponzoni, R.W., Nguyen, N.H., Khaw, H.L., 2007. Investment appraisal of genetic improvement programs in Nile tilapia (Oreochromis niloticus). Aquaculture 269: 187-199.
Ponzoni, R.W., Nguyen, N.H., Khaw, H.L., Ninh, N.H., 2008. Accounting for genotype by environment interaction in economic appraisal of genetic improvement programs in common carp Cyprinus carpio. Aquaculture 285: 47-55.

of countries in which work is being conducted is small compared with the number that could potentially benefit from the development and utilization of improved strains.

We 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 system
3. Formulation of the breeding objective
4. Development of selection criteria
5. Design of the system of genetic evaluation
6. Selection of animals and of mating system
7. Design of the system for expansion and dissemination of the improved stock
8. Monitoring, impact assessment and comparison with alternative programs

Fish rearing

This approach not only enables a logical treatment of the matter, but it also helps identify the areas in which knowledge or its application are deficient, and that should therefore be targeted in research, development and technology transfer. During the implementation of well designed genetic improvement programs, weaknesses, deficiencies and areas where there is room for improvement are frequently identified. Such program limitations provide pointers to potentially useful research areas, which if addressed will provide information that will enable refinements that may further increase the effectiveness of the program. The approach also reflects the philosophy of working right through from the genetic research and development, to the point of impact on the farmers and consumers that benefit from the improved strains.

Limited, and in some cases almost complete lack, of resources can be a serious constraint to the implementation of a genetic improvement program. The limitations are frequently both financial and human. Technical staff involved in aquaculture most often come from a fish biology background and have insufficient training in quantitative genetics. The shortcomings in capacity are more important than the financial limitations because well trained personnel can make important achievements with limited material resources, but no amount of resources will compensate for lack of capacity. Hence, training of local staff in quantitative genetics and animal breeding should be a priority and we continuously make a major effort in this area.

When a genetically improved strain is available, multiplication and dissemination face difficulties due to lack of capacity at the hatchery level. The notion of paying a greater price for stock of greater genetic merit is not frequently part of the culture. Producers often lack both the financial means to acquire fingerlings from hatcheries breeding an improved strain and an understanding of the potential benefits. The sad reality is that we have been more successful at developing improved strains than at achieving impact with them at the producer level. Again, capacity building at the level of hatchery operators and farmers is essential to achieve the desired impact from the genetically improved strains.

HOW IS WORLDFISH SPECIAL IN RELATION TO GENETIC IMPROVEMENT?

Some of the steps listed in the previous section are such that almost exclusively scientific considerations are involved. In those cases WorldFish acts in a way that differs little, or not at all, from any other effective genetic improvement operation in the world. This is true for steps 3, 4, 5, 6 and 8. By contrast, WorldFish is different and particular about steps 1, 2, and 7.

In relation to step 1, WorldFish explicitly focuses on addressing the needs and capacities of smallholders and small- and medium-sized aquaculture enterprises. By increasing productivity and profitability of aquaculture among these groups we believe we can effectively help reduce poverty and hunger. This occurs not only through increasing the availability of highly nutritious food for small producers and their dependents, but also by creating employment throughout the value chain and by generating the surpluses of fish for sale that contribute to reducing poverty and hunger among both rural and urban dwellers.

The issue of species choice (Step 2) is important as it demonstrates WorldFish's approach to genetic improvement. Firstly, we respond to partners' demands; in other words, we work with species that the partner country in question has identified as of importance for aquaculture development. And secondly, we work with species that are either herbivorous or omnivorous, that feed low in the food chain and that do not require a high animal protein diet. We avoid carnivores because they have to be fed diets dependent on increasingly scarce and costly fishmeal, and their overall efficiency in transforming feed into flesh is lower than that of herbivores or omnivores. This issue is intimately related to our focus on smallholders and on small- and medium-sized enterprises.

The desirable fish developed by the genetic improvement program have to reach the farmer (Step 7). This is the area that has generally proved to be the most problematic. The mechanisms whereby this can be achieved are simple in principle, but often difficult to implement in practice because they involve influencing people's attitudes and actions. The

Local farmer at work

involvement of private hatcheries in the multiplication and dissemination phase has been possible in some instances, but the lack of understanding of genetic principles by hatchery managers can be a problem. This is an area that requires much attention because there is no point in having superior fish in the research centers if these do not reach the farmers' ponds.

TOWARDS RESPONSIBLE USE OF IMPROVED STRAINS: THE PRINCIPLES INVOLVED

The general approach we follow is designed to try to ensure that the results of our research, development and technology transfer contribute towards poverty alleviation and reducing hunger among poor fish farmers in developing countries. In pursuing this endeavor, we also consider the need to ensure that while benefiting the poor, the development, multiplication and dissemination of improved fish strains is carried out in an environmentally responsible manner. Actions should be as consistent as possible with the FAO Code of Conduct for Responsible Fisheries[3] , the Nairobi Declaration on 'Conservation of aquatic biodiversity and use of genetically improved and alien species for aquaculture in Africa' and the Dhaka Declaration on 'Ecological risk assessment of genetically improved fish'.

[3] See http://www.fao.org/DOCREP/005/v9878e/v9878e00.htm

The responsible use of improved strains is based upon three main principles, genetic, environmental, and social and humanitarian.

- **Genetic principles.** The gene frequencies of the alleles favored by a selection program in the improved strains will be different from the wild, unimproved populations. Also, when selective breeding incorporates multiple sources of germplasm, the improved strains will have new alleles and may lose rare alleles present in local, wild populations. The genetic risks posed by the development and use of improved strains are of course greater when there are valuable wild populations of the species in question within reach of aquaculture escapees.
- **Environmental principles.** The development, multiplication and dissemination of improved fish strains should be done in a way that minimizes the impact on the environment and on other fish populations.
- **Social and humanitarian principles.** WorldFish uses genetic improvement of important aquaculture species as a means of reducing poverty and increasing food security. It does this by seeking to ensure that smallholders, and small- and medium-sized aquaculture enterprises, benefit from its research and development endeavors. In particular, it is responsive to national government requests for support in developing and using improved strains.

TOWARDS A RESPONSIBLE USE OF IMPROVED STRAINS: THE PRACTICE

The risks involved in the use of improved strains vary widely. Where aquaculture is already being practiced and one or more species are already being farmed, the use of a strain that has superior attributes from a production viewpoint relative to farmers' strains is unlikely to pose additional risks, especially if there are no particularly valuable wild populations of the same species nearby. This would be the case of an improved tilapia strain in many Asian countries. By contrast, where aquaculture is relatively new and there are still wild populations readily accessible by escapees of a genetically improved strain of the same species, the risks are high. The escapees may interbreed with the wild population with unknown but likely undesirable consequences (e.g., loss of the uniqueness of the wild population, change in the fitness of

Dissemination of improved strain

the resulting population with consequences to the ecosystem as a whole). This could be the case of an improved tilapia strain in many Sub-Saharan African countries. These two cases are extreme, and there are many situations that are not so clear cut. For instance, when there are no populations of the same species being introduced, but the introduction could have an ecological impact. There are no universally applicable formulae and each case has to be studied in its own right.

The conduct of systematic environmental risk analyses can be of great value for the identification and subsequent management of the risks associated with development, introduction and dissemination of genetically improved fish strains in a given region. This practice has not been widely adopted for aquaculture beyond disease-related risks. Where the adoption of genetic improvement programs may pose environmental, ecological or genetic risks to local fish populations and indigenous biodiversity, WorldFish actively works with partners towards the development of tools and methodologies that improve local capacity for implementation of environmental risk analyses. WorldFish also encourages input from multiple stakeholders at key stages in the risk analysis process.

WorldFish operates within an overall framework that greatly reduces the risks associated with the use of improved strains. When WorldFish works with a partner country on the development, multiplication and dissemination of an improved strain, it does so on the understanding that all related activities have been approved by the relevant government and non-governmental institutions concerned with this issue. Further details on the points to be considered can be found in the WorldFish document entitled 'Policy on the Transfer of Genetically Improved Farmed Tilapia (GIFT) from Asia to Africa' [4].

CONCLUDING REMARKS

Present genetic improvement programs involve the application of a reliable, proven technology based on quantitative genetics. Central to the success of these programs are continuity of purpose and long term objectives. Genetic technology is extremely powerful but it requires time, and impact cannot be achieved within the standard three year duration of project grants. The dissemination of improved strains for the benefit of aquaculture producers entails more sociology and economics than genetics, and the challenge it poses should not be underestimated. Effective dissemination of improved strains will not occur unless adequate resources are assigned for that purpose.

Spectacular advances are taking place in the area of molecular genetics. At present it is not obvious how such advances will benefit the existing genetic improvement programs for aquatic animals in developing countries. However, we remain open minded and keep up to date with developments in the area. It is likely, in the future, that we will embark upon research phasing in molecular techniques, creating knowledge that will refine and improve current programs. This may enable selection for traits that are difficult to handle with currently used quantitative methods. In this way WorldFish will be able to provide solutions to genetic improvement 'problems' to partner countries in which aquaculture may be at very different stages of development. Note, however, that the quantitative principles in aspects of design and implementation of genetic improvement programs will remain essential. Refinements and enhancements from advancements in molecular genetics may add to the gains currently made, but will not replace the quantitative approach, nor can they be effective in isolation.

[4] http://www.worldfishcenter.org/fishnetcms_d01/resource_centre/GIFT_Africa_Policy.doc

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DEFINITION OF TERMS RELEVANT TO THIS DOCUMENT

The term **fish** is used in a broad sense, to include invertebrate as well as vertebrate aquatic animals.

An **allele** is an alternative form of a gene (one member of a pair) that is located at a specific position on a specific chromosome. For example, the gene for color (albino or normal) in some fish exists in two forms, one form or allele for normal color (A) and the other for albino (a).

Gene frequency is a measure of the relative frequency of an allele at a genetic locus in a population. It is expressed as a proportion or a percentage.

Introgression is the incorporation of genes of one species or population into the gene pool of another by backcrossing of fertile hybrids with either parent species or population. For instance, escaped adults of an improved strain mating with native, wild *O. niloticus* adults could produce fertile hybrids, which could then backcross with more wild *O. niloticus* adults.

Selection is the choice of animals for use as parents.

Selective breeding is the process whereby parents are selected on the basis of one or more criteria, usually related to greater productivity.

A **stakeholder** is an individual, group or organization interested in the issue or sharing a potential burden resulting from a particular decision, such as a decision to introduce a genetically improved strain of fish.

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For further details contact:

The WorldFish Center
PO Box 500 GPO, 10670 Penang, Malaysia
or e-mail: **worldfishcenter@cgiar.org**

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