Msingi

‘Assisting development of Tilapia (O. niloticus) farming in East Africa’

Phase 1: Development of an International Tilapia Genetic Improvement Case Study Assessment Report

February 2018

Prepared by:  - Dr Satya Nandlal (Director, InnAq)
               - Dr Peter B. Mather
               Brisbane, Australia
## Abbreviations

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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>ADB</td>
<td>Asian Development Bank</td>
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<td>AFGC</td>
<td>Akvaforsk Genetics Center</td>
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<td>AKVAFORSK</td>
<td>Institute of Aquaculture Research, Norway</td>
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<td>ASIs</td>
<td>Advanced Scientific Institutes</td>
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<td>BFAR</td>
<td>Bureau of Fisheries and Aquatic Resources, Philippines</td>
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<td>CLSU</td>
<td>Central Luzon State University, Philippines</td>
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<tr>
<td>DEGITA</td>
<td>Dissemination and Evaluation of Genetically Improved tilapia Species in Asia</td>
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<td>EA</td>
<td>East Africa</td>
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<td>EBVs</td>
<td>Estimated breeding value</td>
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<td>FAC</td>
<td>Freshwater Aquaculture Center of CLSU, Philippines</td>
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<td>FGII</td>
<td>Genetic Improvement of Farmed Tilapia Foundation International Incorporated</td>
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<td>FSO</td>
<td>Fish-Farmers Sales Organization, Norway</td>
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<td>GIFT</td>
<td>genetically improved farmed tilapia</td>
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<td>GST</td>
<td>GenoMar Supreme Tilapia</td>
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<td>ICLARM</td>
<td>International Center for Living Aquatic Resources Management</td>
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<td>IDRC</td>
<td>International Development Research Centre, Canada</td>
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<td>MAS</td>
<td>Marker Assisted Selection</td>
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<td>NARS</td>
<td>National Aquatic Research Systems</td>
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<td>NFFTC</td>
<td>National Freshwater Fisheries Technology Center of BFAR, Philippines</td>
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<td>NOK</td>
<td>Norwegian krone (currency)</td>
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<td>NSFI</td>
<td>Norwegian Salmon-Farming Industry</td>
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<td>QTLs</td>
<td>Quantitative Trait Loci</td>
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<td>R &amp; D</td>
<td>Research and Development</td>
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<tr>
<td>RIFF</td>
<td>Research Institute of Freshwater Fisheries, Indonesia</td>
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<td>SSD</td>
<td>Sexual size dimorphism</td>
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<td>TA</td>
<td>Technical assistance</td>
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<td>TGC</td>
<td>Thermal Growth Coefficient</td>
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<td>UNDP</td>
<td>United Nations Development Program</td>
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<td>WF-</td>
<td>WorldFish Centre, Malaysia</td>
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## Glossary

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<tr>
<td><strong>Base population</strong></td>
<td>Randomly mating population of fish used as the basis for subsequent selective breeding, selection experiment or selection program</td>
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<td><strong>Biosafety</strong></td>
<td>Provision of safeguards for the health and survival of biodiversity, both wild and farmed</td>
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<td><strong>Breed</strong></td>
<td>A distinct group of a farmed or other domesticated species, descended from common ancestors and having visibly similar characteristics</td>
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<td><strong>Breeding history</strong></td>
<td>Genetic lineage of an individual or population</td>
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<td><strong>Breeding program</strong></td>
<td>Management of broodstock and individual breeders over successive generations so as to improve desirable traits that are largely or exclusively genetically determined, i.e., heritable</td>
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<tr>
<td><strong>Broodstock</strong></td>
<td>Captive population of fish, kept for breeding purposes or for mass production of fish seed for farming or release</td>
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<tr>
<td><strong>Cryopreserved sperm</strong></td>
<td>Fish spermatozoa, stored in liquid nitrogen</td>
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<td><strong>Dam</strong></td>
<td>Female parent</td>
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<tr>
<td><strong>Dressing weight</strong></td>
<td>Weight of the marketable component of a harvested fish after parts unwanted by humans (usually the viscera) have been removed</td>
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<td><strong>Family selection</strong></td>
<td>Selection based on information from full sibs and/or half sibs to estimate breeding values (may include information from other relatives). The selection is among families and not within family since no information is available to distinguish between family members. Method requires that information on relatives are recorded, which means that full sib groups must be reared separately until fish have reached a size for which a marking systems can be applied</td>
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<tr>
<td><strong>Fingerling</strong></td>
<td>Young fish about the length of a human finger</td>
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<tr>
<td><strong>Fish seed</strong></td>
<td>Early life history stages of fish (eggs, larvae, fry, and fingerlings) that are raised in hatcheries or collected from the wild for use by farmers</td>
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<td><strong>Founder population</strong></td>
<td>Sexually capable individuals that comprise a new population established for breeding purposes</td>
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<tr>
<td><strong>Fry</strong></td>
<td>Young fish of very small size, usually only a few centimetres in length</td>
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<tr>
<td><strong>Full sib</strong></td>
<td>Offspring that come from the same sire and dam i.e., same parental pair</td>
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<td><strong>Gene bank</strong></td>
<td>A facility established for the <em>ex situ</em> conservation and use of genetic material, e.g., for fish, collections of broodstock and/or cryopreserved sperm of different strains</td>
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Genetic characterization  Identification of individuals and populations using morphological, metric, and/or molecular markers

Genetic modification  Artificial transfer of specific genes from one taxon to another. New organisms produced are referred to as Genetically Modified Organisms (GMOs)

Genetic variability  Total amount of genetic variation in a population, conferring scope for future adaptation via natural selection and for improvement of specific commercial traits via selective breeding

Genomic selection  The complete genome of Atlantic salmon was mapped and published in 2014. Analysis of SNP’s (single sites on the genome that are variable) allows relationships between variation in markers and QTLs we want to improve (e.g. resistance to selected disease) to be correlated, mapped and applied as markers in breed improvement programs.

Generation interval  Average age of parents at birth of offspring

Germplasm  A general term for genetic material, usually in the form of whole living organisms or as gametes (eggs and/or sperm) or embryos, used for breeding purposes, conservation and/or research

Half sib  Offspring from a single sire (i.e., paternal half sib) or single dam (i.e., maternal half sib). This means that within a half sib family some fish may also be full sib, e.g., when one sire is mated to two dams

Heritable  Refers to a trait or character that is inherited by progeny from their parents

Hybrid vigour  Substantial improvement of one or more performance traits in hybrid progeny compared with measurements of the same in their parents

Hybridization  The mating of parents of different strains, breeds, species or, in rare cases, higher taxa to produce crossbred individuals or populations.

Inbreeding  Mating together of individuals that are related to each other by common ancestry.

Individual selection  Selection based on relative e performance of single individuals. This method does not require a marking system, but the number of offspring from each family that are allowed to contribute their genes to the next generation must be controlled in order to limit inbreeding.

Local adaptation  Increased fitness of a population that has adapted to specific local environmental conditions.

Quantitative genetics  A sub-discipline of genetics that deals with quantification of production traits in breeding
Quantitative Trait Loci (QTL) are regions in the genome that govern a particular trait or property to a large degree. These regions are delimited areas that can be evaluated to select individuals with desired traits. In the context of salmon resistance to viral disease, IPN (Infectious Pancreatic Necrosis), these regions are crucial for selecting fish with IPN resistance.

Selective breeding involves choosing the best-performing individuals from families to become parents in the next generation. This is more commonly called selection.

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<td>Sire</td>
<td>Male parent</td>
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<tr>
<td>Strain</td>
<td>Distinct variety of a farmed or other domesticated species</td>
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<tr>
<td>Trait</td>
<td>A detectable attribute of farmed or other domesticated organisms, e.g., fast growth, body shape etc.</td>
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The Thermal Growth Coefficient model is a tool used in production planning to predict growth rates of fish under different temperatures. Growth data collected at one temperature can be used to predict growth at other temperatures. However, note that this model is not applicable across the full range of conditions for farmed fish, particularly at the lower end of the temperature range, where growth rate increases with temperature but reaches a peak at an intermediate temperature and then declines.
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Summary

In general, most fish, mollusk and crustacean farm stocks around the world are unimproved and can also be highly inbred and as a consequence, often show relatively poor culture performance. This has rapidly encouraged interest in farming genetically-improved stocks around the world. Appropriate breeding objectives are a prerequisite for development of any genetic improvement program. Breeding objectives define the target traits to be improved and assign an economic value or desired gain to each trait identified. The economic values and/or desired gains are derived from in-depth analysis of prevailing production systems, and their social and economic context.

The major move towards implementing genetic improvement programs in aquaculture using modern quantitative genetic tools was initiated and developed for Atlantic salmon and Rainbow trout in Norway in the 1970s by the Institute for Aquaculture Research (Akvaforsk) following many years of experience with stock improvement of terrestrial livestock species. The Atlantic salmon program in Norway is the longest continuous running program conducted on any aquatic species around the world and has provided the modern benchmark, and is now a model for other stock improvement programs on aquatic species. Improved, farmed Atlantic salmon can now be produced to market size in approximately half the time and at half the cost when compared with unimproved farmed stocks.

Tilapia farming in Asia began to expand significantly in the 1970s linked to region-wide advances in hatchery technologies and improvement in pond management. Genetic aspects of tilapia farming however, were largely neglected prior to the 1980s. By this time, the consequences of a lack of attention to genetics was beginning to be reflected in stagnating tilapia farm yields. In response, the International Center for Living Aquatic Resources Management (ICLARM; now the WorldFish Center), Akvaforsk and research partners in the Philippines proposed an international research and development effort on genetic improvement of farmed tilapias. The move to develop improved farm strains of tilapia resulted from selective breeding efforts to develop Genetic Improved Farmed Tilapia (GIFT) (1988-1992, Phase 1), that was made possible via a technical assistance (TA) program funded by the Asian Development Bank (ADB), the United Nations Program (UNDP), and participating institutes. UNDP provided further TA for the development of GIFT (1993-1997, Phase 2), which led to establishment of the International Network of Genetics in Aquaculture (INGA) and Genetic Improvement of Farmed Tilapia Foundation International Incorporated (GFII). In parallel, ADB and other agencies provided further TA from 1994 to 1997 to disseminate the GIFT strain to a number of regional countries interested in ongoing breeding work with the GIFT strain. Accordingly, WorldFish in Malaysia and many other institutions received GIFT stock from both the 6th and 8th GIFT generations. At the same time, rights to the GIFT fish were handed to GFII to continue the research program and to market the fish. GFII was not however, wholly successful and to remedy this, GFII entered a collaborative program with GenoMar ASA- a Norwegian private company. GenoMar acquired commercial rights to the GIFT strain and continued with the breeding program and entered into commercial ventures using their trademark name, GenoMar Supreme Tilapia in the Philippines, Brazil and China. The company continues research and development that began under GFII and this resulted in privatised strains notably; GST, GET EXCEL that are now farmed by large private companies, e.g. Progift Nile Tilapia in China.

The collaborative research project for the genetic improvement of Nile tilapia (Oreochromis niloticus), i.e., GIFT strain indicated the potential for increased production from selective breeding. In its sixth generation of selection, the GIFT strain had demonstrated 77% faster growth and 60% higher survival compared with farmed strains in the Philippines. Subsequent evaluation of the second generation GIFT strain in Bangladesh, China, Thailand and Vietnam showed that the GIFT strain achieved higher growth
rates than local strains, differences ranging from ~18% in China to ~66% in Bangladesh. Analysis of overall potential impact of farming improved fish indicated that the adoption of an improved strain would result in reduced cost of production and increased total fish production.

Following from above, the GIFT strain has been maintained intensively and actively managed in captivity by professional applied geneticists and fish breeders over many generations. Exposure to multiple generations of family selection since the late 1980s has improved growth rate significantly in relation to most cultured stocks by more than 60 % and even to ~100 % in some comparisons. GIFT fish can grow to more than 800gm over 10 months under good production conditions. Despite some loss in starting levels of genetic diversity, a natural outcome of the selection process, rates of genetic gain in performance remain in excess of 10% per generation. These developments resulted in tilapia farming not only becoming one of the fastest-growing industries in the modern aquaculture sector but in addition, tilapia has become an international fish commodity. In SE Asia, tilapia farming is a major contributor to this phenomenon and has developed mainly based on a single species, Nile tilapia. Expansion of the tilapia industry over the last 30 years can be attributed to several factors that favour production of this species of which the most important has been use of selective breeding programs to develop genetically improved strains that resulted in widespread dissemination, and commercialization of improved farm strains.

The ongoing program of research and breeding of GIFT (6th generation onwards) then moved with WorldFish to Malaysia in 2002. At WorldFish, the GIFT breeding program continued selection of live weight at harvest to further improve growth rate. The GIFT strain has subsequently been exposed to seven additional generations of selection since it was relocated to Malaysia.

Following introduction to Malaysia, the GIFT strain has been disseminated to nine countries in Asia and Latin America. The program is now well positioned to consider incorporating new traits into the breeding objectives (i.e. flesh quality, disease resistance, some behavioural traits). WorldFish scientists however, have recently stated that they face major challenges with further development of the strain.

In parallel with development of GIFT, a tilapia improvement program that led to development of the Akosombo strain was started in 1994 by the Aquaculture Research and Development Centre (ARDEC-CSIR- Water Research Institute-WRI), Akosombo, Ghana. This synthetic strain subsequently became the nucleus for a breed improvement program for the region. The Akosombo tilapia strain achieved growth rates 30% to 50% above those of other local tilapia farm strains in Ghana. While Ghana did not receive GIFT fish until 2011 (initially introduction of GIFT was banned), GIFT technology was used to develop the Akosombo strain. In addition, WorldFish funded a number of breeding programs and training in Ghana. The GIFT program therefore provided indirect benefits to Ghana via use of GIFT technologies and expertise. A general lack of infrastructure across the region however, has limited efforts to expand tilapia farming geographically across the region.

Successful stock improvement programs have been undertaken around the world that have improved the productivity of certain farmed tilapia stocks including for Nile tilapia. The organizations involved and the approaches they adopted in such programs can provide models for determining how best to assist with developing and implementing a stock improvement program for the indigenous Nile tilapia (Oreochromis niloticus) in EA. Developing appropriate breeding objectives that maximize economic returns will be a prerequisite for sustainable genetic improvement programs for smallholder production of Nile tilapia across this region.

To date, relatively few stock improvement programs have been conducted in Africa on the indigenous Nile Tilapia, but of the few selective breeding programs that have been undertaken on Nile tilapia
strains some have resulted in improved strains notably; the Abbassa and Akosombo strains. Genetic gains achieved in some programs however, were often lost or reduced later when improved stocks were tested in less favourable farm environments. This reinforces the idea that growth performance, even of improved strains, can be impacted significantly in suboptimal culture environments because it can be significantly impacted by genotype by environment effects (G x E).

A variety of reports have indicated that improved farm performance of Nile tilapia can be achieved in Africa via genetic improvement when local African strains are improved. Existing improved strains (e.g. GIFT strain) that are based on wild and farmed founding stocks that are not indigenous to a particular region are best avoided as base populations for new stock improvement programs where there are indigenous wild populations as they have the potential to pose risks to the genetic integrity of local wild tilapia populations. A more conservative, but rationale approach, will necessitate development of local breeding programs to develop improved strains from indigenous stocks for specific target regions.

In EA where there is a recognised need to increase fish production and to improve livelihoods of local people, Nile tilapia are growing in importance as a farmed aquatic species and farmers utilise a variety of locally available farm resources to produce them. Since production systems can vary considerably, breeding objectives are likely to differ depending on the farming conditions/systems employed.

Some lessons and recommendations that we draw from this study include:

Fish are a critical source of animal protein to the people of EA, and fishery resources play a central role in sustaining rural and urban livelihoods across much of the region. Yet for the region as a whole per capita supply is declining and current projections of supply and demand indicate that this gap will continue to grow in coming decades. If this gap is to be bridged, then capture fisheries need to be sustained and the potential of aquaculture developed and expanded. In doing so, attention needs to be given to protecting the rich aquatic biodiversity of EA especially the freshwater fish biodiversity and its role in sustaining capture fisheries and providing species for aquaculture.

Aquaculture is a relatively new farming activity in much of EA and the region’s production of farmed-raised fish remains low. While there are many reasons for this, among the most important are poor management practices and the use of poorly domesticated stocks. To address these constraints, a greater range of management practices and approaches need to be considered. These should include improved pond and broodstock management and use of better performing breeds/strains. In doing so, however, these approaches need to be adapted to the local social, economic, institutional and biophysical context. While improved strains have potential to improve production there is clear risk of improved fish escaping into the wild and contaminating native fish populations and thus affecting local biodiversity. In light of these considerations, we recommend Msingi to develop guidelines that will foster the development of aquaculture while conserving local biodiversity. An example of guidelines or protocols for biosafety and safe sharing of fish germplasm that include quarantine and environmental safeguards are ones developed by INGA (refer to Appendix 1).

Given that aquaculture from small scale, low-input systems to large-scale intensive systems can achieve potential benefits from genetic enhancement, quality seed should be made available and used in conjunction with proper broodstock and farm management in EA.

Genetic resources in cultured populations can be degraded as a result of captive breeding, so genetic aspects of broodstock management need to be a basic element within all types of aquaculture and stock enhancement systems.
Introductions of fish, including genetically improved strains can play a role in development of aquaculture. Any movement of fish between natural ecological boundaries (e.g. watersheds) may involve risks to local biodiversity and so there will be a need for refining and wider application of biodiversity protocols, risk assessment methods, and monitoring programs for introductions of fish, including genetically improved species and alien species. EA countries have important responsibility in the development and implementation of such protocols and associated regulations, the establishment of clear roles and responsibilities, and capacity building. Such efforts should be linked to obligations pursuant to the Code of Conduct for Responsible Fisheries, the Convention on Biological Diversity, and other relevant international agreements.

Unique wild stocks of important tilapia species still exist in many parts of EA. This recognition is based on experience in the original GIFT program that suggested unique (genetically distinct) wild stocks of Nile tilapia are present at least in major river drainages across northern and western Africa but wild stock status has yet to be assessed in EA. Until the status of wild stocks have been investigated adequately across this region, the conservative approach would be to assume that there will also be unique stocks present there given the distinct lacustrine and riverine habitats present. We suggest priority areas for conservation in EA should be identified and managed where introductions of alien species and genetically altered species should potentially, be restricted.

The majority of issues and problems associated with movement of fish and the use of genetically improved or altered species are common to most African countries. We therefore encourage Msingi to look for examples of workable policies and legislation, adopt them where appropriate to fill national policy gaps, and harmonize them where necessary. In addition, existing regional bodies or new bodies can assist in coordinating translocation activities taking into account ecological realities, in particular, transboundary watersheds.

While some baseline information on fish genetic diversity, environmental integrity and aquaculture practices exist in EA countries, these are neither comprehensive nor easily accessible. The existing mechanisms for collection and dissemination of information on fish genetic diversity, environmental integrity and aquaculture practices will need to be strengthened.

Internationally accepted codes and protocols for reducing the risk of transboundary movement of pathogens (including parasites) via movement of fish including alien species do exist, but they do not address any specific needs regarding genetically improved (altered) species. We believe Msingi in collaboration with other relevant bodies in EA should evaluate the existing codes and protocols for reducing the risk of transboundary movement of pathogens (including parasites) and adapt them for EA local conditions.

Policymakers, enforcement agencies, stakeholders and the general public need to be made aware of issues related to, and the need for, policy on the movement of alien species and genetically improved (altered) species, and this should be high on national agendas.

Some policies relevant to movement of fish seem difficult to implement, are unknown to users, create conflicts of interest, or are viewed as restrictive, in part because they have been developed with limited consultation and participation. Formulation of policy and legislation concerning fish movement should seek to engage all stakeholders in a participatory process and use organizations such as, or similar to, formation and functions of INGA. This is because fish genetic resources conservation and sustainable use are complex objectives that requires international collaboration. It should be noted that since its inception, INGA made significant progress with; assisting member countries in developing national breeding programs, initiating two regional research programs for genetic improvement of carps and Nile tilapia, assisting transfer of germplasm between member countries for
research and to disseminate improved strains, assisting formation of national genetics networks, assisting capacity building for developing country scientists, and providing information on genetics research and policy issues in biodiversity conservation, intellectual property rights, etc. In light of this, we suggest Msingi in collaboration with EA government aquaculture agencies/departments should establish advisory groups with links to independent and scientifically competent expert bodies potentially including; WorldFish, Akvaforsk, FAO, and IUCN.

Although economic benefits can be derived from the use of genetically improved fish stocks in aquaculture, in many cases, those to whom benefits accrue do not bear the costs associated with adverse environmental impacts. In view of this, there should be consultation among stakeholders in EA for provision for liability, compliance (e.g., incentives), and restoration within policies and legislation concerning the movement and use of genetically improved fish species in aquaculture.

After careful review of the four tilapia stock improvement programs and their associated organisations reviewed here, we consider the most relevant organisation to assist in a tilapia stock improvement in an EA context to be Akvaforsk (now NOFIMA Marin). The Nofima Food Research Institute was established on 1 January 2008 and in 2011 changed from a corporate group to NOFIMA AS – a limited liability company. Akvaforsk has a long tradition of successful research and development dating back to 1931. It is currently one of Northern Europe’s largest and most successful industry-orientated research institutions and focuses its expertise in the areas of fisheries, aquaculture and associated food industries. It is worth noting however, that Nofima’s current focus has changed somewhat from the original focus at Akvaforsk to be now more directed at commercial returns from projects rather than necessarily including broader goals associated with stock aquatic improvement capacity building and partnering other groups undertaking this work. Issues that we believe may require specific consideration in this regard by Msingi if Nofima were selected to contribute to the Msingi program in EA include;

- Relative costs of engaging NOFIMA AS is likely to be higher than an equivalent program engagement with WorldFish Centre because WF can potentially leverage international development opportunities.
- Capacity building of EA and other regional staff and facility and infrastructure development will be critical to long term and ongoing sustainability of the program, and hence identifying ways to achieve this with NOFIMA AS and relevant governmental institutions we consider to be important at the start of the program.
- Identifying and supporting local regional scientists and animal breeders to develop their academic and technical expertise in various aspects of stock improvement and associated technical areas we believe should be built into the main project and will be critical to long-term success of the project. If this cannot be achieved directly via NOFIMA AS engagement, then finding additional partners (potentially Stirling, Auburn and/or Wagenerin Universities) to provide capacity building in specialist areas, we believe should be considered. This is also crucial to long-term sustainability of the program beyond the time when an improved EA line is available locally and will potentially address problems where the improved strain is not adequately maintained after project partners have concluded their engagement.
- A number of successful stock improvement programs in Asia and the Pacific region (and elsewhere) have not been successful over the longer term simply because local capacity to maintain and extend the programs was not addressed at the time. As an example, there have been a number of attempts by both government and private producers to develop improved strains of farmed *O. niloticus* in Malaysia and Indonesia that while initially successful, later failed due to poor stock management or a lack of ongoing support from fish breeders with appropriate background in stock improvement technologies and approaches.
In the GIFT program, this issue was addressed at least in part, by engagement with local and international universities (U. Philippines and U. of Wales) from the time the project first commenced.

We consider the only potential alternative project partner to NOFIMA AS is WorldFish Centre. We note however, that there has been a significant turnover in relevant staff at WorldFish over the last 5 to 10 years and as a result, much of the critical practical expertise developed in fish stock improvement in the various stages of the GIFT programs and related projects is now significantly degraded in the organisation. For this reason, we believe that WorldFish has less to offer than it once did with the exception, that if Msingi decides that the starting point for the EA project will be existing stocks of GIFT (improved >Gen9), rather than developing a local EA Nile tilapia strain directly, then obviously having WorldFish involved from the start would be critical to the success of this option.
1.0 Background

Msingi is a pioneering industry development and investment organisation in EA that aims to support growth of competitive industries across the region. Msingi identifies industries across the region that they consider to have a comparative advantage and supports their growth via investment and technical assistance to pioneer businesses and wider support to the industry.

1.1 Msingi Aquaculture program

Aquaculture is Msingi’s first industry program, and was launched in 2016. This industry was selected after rigorous analysis because Msingi believes East Africa has a strong comparative advantage and can support rapid growth. EA has excellent natural water resources and appropriate climate for fish farming and is home to many Tilapia species. The region also has rapidly growing human populations and associated increasing demand for animal protein.

Due to stagnant wild local fish catches in EA, demand for fish protein is currently being met from expanding imports. Domestic aquaculture could however, play a much larger role in supplying fish protein to local markets via development of both large and small-scale production. Under the right conditions Msingi believes that the industry could grow from current nascent production levels of 10,000-15,000 mt per annum to at least 220,000 mt over the next decade. Msingi’s aim is to support the growth of a competitive, inclusive and resilient regional industry. The Msingi aquaculture program has a mandate to work closely with the local industry on developing targeted interventions in support of this aim.

1.2 Global context of aquaculture development

Fish are particularly important in the diets of people in the world’s poorest countries, supplying more than 50% of their animal protein intake. Attention to fish production and consumption is vital to achieving one of the Millennium Development Goals that of eradicating hunger. Enhancing access of the poor to the food they need and creating livelihood opportunities to hasten their exit from poverty are part of the current fight against global hunger and extreme poverty.

Fish farming has expanded more rapidly than any other animal food-production sector across the world. Between 1970 and 2000, global aquaculture production grew at an average annual rate of 9.2%, compared with only 1.4% for capture fisheries and 2.8% for terrestrial farmed meat production. In 2000, global aquaculture production was 45.7 million metric tons (t), valued at $56.5 billion. Finfish accounted for 23 million tons, or approximately half of total world aquaculture production. Over the past three decades, aquaculture has expanded, become more intensified, and made major technological advances and recent increases in per capita food fish supply have come mainly from farmed fish.

1.3 Relevance of Genetic improvement in Aquaculture

Most farmed fish have had only very short histories of domestication and genetic improvement, and many still resemble closely their wild relatives. Until quite recently, most farmed fish came from wild seed (fry or fingerlings) or from the progeny of captive spawners that were managed with little or no direct application of genetics. Production of fish seed in hatcheries and the ability to grow successive generations of broodstock to sexual maturity began in the 1970s for Atlantic salmon and Rainbow trout in Norway and for most Chinese and Indian carps, and farmed shrimp (Penaeidae) in the 1980s, followed by milkfish (Chanos chanos) in the 1990s. The world’s first International Symposium on Genetics in Aquaculture was convened in 1982. Until the mid-1980s, most aquaculture research and
development (R&D) had been targeted at improving seed production technology and better fish husbandry rather than at genetic stock improvement.

1.4 Msingi’s strategy to support an EA genetic improvement program

Genetics is important because it can directly impact industry competitiveness due to lower costs of production and better asset utilization. This in turn results from better growth rates, improved feed utilization and higher disease resistance etc. In EA to date, there has been only very limited attempts to improve stocks of farm fish so local farmers essentially use wild genetics. Indications that local farm stocks are not highly productive include statistics from farmers that use a 9-month growth cycle to reach approximately 500gm even with high quality feed. Hatchery management also needs improvement as fingerlings are often undernourished, sick and have a lower % male than is considered optimal.

The Msingi Aquaculture Team will support development of a sustainable genetic improvement program for EA via providing the required technical expertise and/or capital investment to produce highest quality tilapia in EA. Their genetics strategy is divided into four main phases:

1) **Analysis of a range of case studies of tilapia genetic improvement programs across the world**
   To understand critical success (or failure) factors, strengths and weaknesses, and key ‘learnings’ for an East African genetic improvement program. This will also involve an assessment of the strengths and weaknesses of various international players in tilapia genetic improvement.

2) **Assessment of the existing capacity and resources in East Africa for a tilapia genetic improvement program,** including assessments of (i) the performance to date of the local genetics in use in EA aquaculture; (ii) private and public sector capacity in EA for managing a high quality genetic improvement programme; (iii) any key policy considerations relating to genetic improvement in EA; (iv) development of recommendations for the design and implementation of a genetic improvement programme in EA, based on the above.

3) **Scoping and development of partnerships for genetic improvements in EA,** including with local and international organisations, as recommended in 2) above.

4) **Detailed planning and implementation of selected options** working alongside selected partners to develop and implement detailed feasibility work and business plans for investment(s)
2.0 Purpose and method of study

2.1 Purpose of study

Msingi has thus far convened two annual meetings of commercial aquaculture producers in East Africa and will continue to develop this platform. From this platform, Msingi has identified five key focus areas for support and improvement: (i) aqua feed; (ii) capacity among producers; (iii) fingerlings & other inputs; (iv) market and distribution-related issues; (v) industry coordination and government/donor support. Msingi is now in the process of developing and implementing interventions in each of these areas, commencing with an international tilapia genetic Improvement Case study Assessment that forms the focus of the current report.

2.2 Methods and sources

The objectives of the current study are outlined in TOR Schedule 1 - The services, page 13 and 14. Qualitative and quantitative methods were used, namely (i) reviews of existing studies and secondary documents; (ii) in-depth interviews/exchange of information between consultants and key Msingi staff. Specifically, the focus of the current study Phase 1 task 3 was addressed via gathering and reviewing of existing studies and secondary documents from published sources, media reports and personal knowledge/experience etc. about the selected organizations and their individual stock improvement programs, in addition to information available from web sites and unpublished information from institution libraries. The report follows the following general structure; a review of all available information on each program and organizations involved (the GIFT project by WorldFish Centre, the salmon genetic improvement project by Akvaforsk, the Akosombo tilapia strain program by ARDEC and the Progift program by Progift Aquaculture, China). Analysis of the broad issues was based on in-house discussions and from knowledge and interactions with past contacts from our individual associations (Satya Nandlal – Fiji Full Member representative; Peter Mather – QUT Associate member representative) with the INGA network developed by WorldFish Centre.

2.3 Report Structure

The report begins with a summary of the selected genetic improvement programs and includes pertinent lessons, and also provides recommendations for future action relevant to the application of genetics in aquaculture in East Africa by Msingi. Programs reviewed include; Genetically Improved Farmed Tilapia (GIFT), Akvaforsk Atlantic salmon genetic improvement, Akosombo Tilapia strain and Progift Tilapia. We discuss keys features of each program including; objectives, location, relevant wider aquaculture industry dynamics, overall business model and funding, technical strategy of the genetic improvement programs, genetic improvement outcomes, lessons learned and implications. The report summarizes (a) focus and approaches of the organizations followed by, (b) strengths and weaknesses. The report concludes with our appraisal of the most relevant organization in the EA context.

Complementary information on the International Network on Genetics in Aquaculture (INGA) and the Genetic Improvement of Farmed Tilapia Foundation International Incorporated (GFII), are provided in Appendix 1.
3.0 Review of selected Genetic Improvement programs

3.1 Genetically Improved Farmed Tilapia (GIFT)

A. Objectives of the genetic improvement program

i) To develop methods for genetic enhancement of tropical finfish
ii) To develop improved breeds of Nile Tilapia (*O. niloticus*)
iii) To build capacity of national institutions in aquaculture genetics research;
iv) To disseminate improved strain (GIFT strain);
v) To carry out genetic, socioeconomic, and environmental evaluation of GIFT
vi) To facilitate development of national tilapia breeding programs.

B. Location and geographic scope of the program

The project was undertaken by International Centre for Living Aquatic Resources Management (ICLARM), now WorldFish Centre in collaboration with the Norwegian Institute of Aquaculture Research-AKVAFORSK, now NOFIMA Marin, and three national institutions in the Philippines (The Philippine Bureau of Fisheries and Aquatic Resources BFAR, Marine Science Institute of the University of the Philippines UP-MSI and Freshwater Aquaculture Center of the Central Luzon State University FAC-CLSU at BFAR.

C. Relevant wider aquaculture industry dynamics relating to the program

The GIFT project commenced in 1988 and was completed in December 1997. Over this period, a collaborative public-sector initiative developed the GIFT strain that performed significantly better than existing farm strains in the Philippines, and a general approach to selective breeding was developed with technical support from Akvaforsk that could be applied more widely for genetic improvement of tropical finfish.

Analysis of overall potential impacts of farming the GIFT strain in five Asian countries (Bangladesh, China, Philippines, Thailand and Vietnam) has shown significant productivity increases and flow-on effects on general fish production in each representative country, enhanced general profitability of fish farming, a decrease in unit price of tilapia in local markets, an increase in local consumption levels of tilapia and other fish by non-fish producing consumers and farmers in addition to, improvement in general economic welfare of people involved.

The GIFT program also resulted in establishment of the International Network on Genetics in Aquaculture group (INGA). INGA then linked with 11 advanced world scientific institutions working in applied genetics of aquatic species. Eleven technologically advanced institutions around the world were later awarded Associate Member status and encouraged to develop research and technology transfer arrangements with INGA country member institutions to increase synergy, capacity building and general outputs.

Research and cooperation between INGA partners and institutional partners led later to establishment of the GIFT Foundation International. The purpose was to support ongoing applied genetics research and development and wider dissemination of the GIFT strain. To meet objectives, the Foundation established alliances with private-sector hatcheries for seed production and distribution, technology transfer to farmers, and related industry
development activities. The Foundation also entered into formal licencing arrangements with seven privately owned tilapia hatcheries in the Philippines. This was the first initiative to establish a non-profit foundation to continue research initiated by WorldFish and its partners. All project partners were members of the Board of the Foundation (refer to Appendix 1 for more details). Selection technologies developed and implemented in the GIFT program were also extended to five species of carps in six Asian countries (Bangladesh, People’s Republic of China, India, Indonesia, Thailand and Vietnam).

In general terms, the GIFT program was very successful. This was evident from ongoing and expanding demand for the GIFT germplasm from other countries and also use of technologies by other developing nations who were not part of the original project. As an example, GIFT strain was introduced to Indonesia by the Research Institute for Freshwater Fisheries (RIFF) facilitated by INGA, and this essentially rescued the local freshwater aquaculture industry that had been in significant decline. Superiority of the GIFT strain attracted attention from both small and larger-scale farmers in Indonesia and culture of tilapia spread widely after GIFT was brought into the country.

Research partnerships developed in the GIFT program also promoted on-going capacity building in national institutions via training programs, workshops and scientific exchanges etc. For example, an intensive training program in ‘Quantitative Genetics and its Application in Aquaculture’ was organized in 1995 for aquaculture geneticists from 13 Asian and African developing countries and this has since been continued and expanded by INGA.

Since 1995, 219 individuals from 28 countries in Asia, Africa, and Latin America have benefited from training conducted under the auspices of INGA. INGA has also assisted its tilapia-farming member countries in development of national breeding programs. In Bangladesh, Fiji Islands, Philippines, Thailand, and Vietnam, breeding programs and related applied genetics research are now based mainly, or exclusively, on GIFT or GIFT-derived strains and on technologies used to develop GIFT. GIFT is also used extensively in research for development of tilapia farming in China, Indonesia, and Malaysia. INGA, moreover facilitated implementation of ADB-financed regional TA for the genetic improvement of carps in Asia that followed largely the same approaches as were used for development and dissemination of GIFT

D. Overall business model and funding:
• Overall structure and approach
  The Asian Development Bank (ADB) supported research and development (R&D) and dissemination of the GIFT fish by providing technical assistance (TA). This TA supported an International R&D effort that was coordinated and executed by ICARLARM.

Prior to initiation of the project, extensive consultations were held between ICARLARM, participating institutions in Asia and Africa, representatives of advanced scientific institutions and donor institutions to develop detailed work plans and approaches. An advisory panel of eminent applied geneticists was invited to undertake frequent reviews of the project as it progressed and to provide guidance on how the project should best be implemented. A Memorandum of Agreement (MOA) specifying the responsibilities of each of the partner organizations, control and use of improved germplasm and the data generated was developed and signed by all program institutions. Over the duration of the GIFT project, ICARLARM employed a consultative management approach and established a Project Management Committee comprising representatives of the various partner institutions.
• **Organizations involved**
  - International Centre for Living Aquatic Resources Management (ICLARM)
  - Norwegian Institute of Aquaculture Research-AKVAFORSK
  - The Philippine Bureau of Fisheries and Aquatic Resources (BFAR)
  - the Marine Science Institute of the University of the Philippines (UP-MSI)
  - Freshwater Aquaculture Center of the Central Luzon State University (FAC-CLSU)
  - Bangladesh: Bangladesh Fisheries Research Institute (BFRI)
  - People’s Republic of China: Shanghai Fisheries University; Freshwater Fisheries and Research Centre (FFRC), Wuxi.
  - Côte d’Ivoire: Centre National de Recherche Agronomique (CNRA), Bouake
  - Egypt: Central Laboratory for Aquaculture Research (CLAR) and Suez Canal University
  - Fiji: Naduruloulou Aquaculture Centre, Ministry of Agriculture, Fisheries and Forestry
  - Ghana: Water Research Institute (WRI)
  - India: Central Institute of Freshwater Aquaculture (CIFA); National Bureau of Fish Genetic Resources (NBFG); University of Agricultural Sciences (UAS), Bangalore
  - Indonesia: Research Institute for Freshwater Fisheries (RIFF)
  - Kenya: Baobab Farms
  - Malawi: University of Malawi
  - Malaysia: Universiti Malaya
  - Philippines: Bureau of Fisheries and Aquatic Resources (BFAR); Freshwater Aquaculture Center/Central Luzon State University (FAC/CLSU); Marine Science Institute of the University of the Philippines
  - Senegal: Department of Fisheries
  - Thailand: National Aquaculture Genetics Research Institute (NAGRI)
  - Vietnam: Research Institute for Aquaculture (RIA) No. 1; Research Institute for Aquaculture (RIA) No. 2
  - Australia: Queensland University of Technology (QUT)
  - Belgium: Musée Royal de l’Afrique Centrale
  - Germany: University of Hamburg
  - Hungary: Fish Culture Research Institute
  - Israel: Agricultural Research Organization
  - Italy: FAO of the United Nations
  - Japan: National Research Institute of Aquaculture
  - Netherlands: Wageningen Agricultural University
  - Norway: AKVAFORSK (Institute of Aquaculture Research, Ltd.)
  - Philippines: Southeast Asian Fisheries Development Center, Aquaculture
  - United Kingdom: University of Wales Swansea and University of Stirling

• **Value proposition**
  From incorporation in the Philippines in 1977, ICLARM (now WorldFish Center) focused its strategic attention on inland aquaculture research and assisting development of tilapia farming. In the Philippines, ICLARM established close partnerships on tilapia research with FAC and NFFTC in BFAR. In 1979, ICLARM and FAC-CLSU initiated genetics research on Nile tilapia to improve the genetic quality of local broodstock via trialling hybridization. This research was undertaken in response to growing concerns in the local tilapia industry and to problems faced by farmers that included inadequate seed supply and deteriorating growth rates under a variety of production systems. They also completed genetic characterisation studies that indicated that quality of farmed tilapia stocks in the Philippines was generally poor. In response, government institutions and international organizations sought financial support to undertake strategic
research programs to develop improved culture strains similar to those developed on crop species.

In 1987, ICLARM convened a pivotal workshop for tilapia researchers from Africa, Asia, Europe, Israel, and North America, at which the urgent need for genetic improvement of farmed tilapias in Asia was confirmed. The International Development Research Centre of Canada (IDRC) at the time was supporting a variety of aquaculture genetics research projects in Asia, linked by a short-lived, regional network. ICLARM and AKVAFORSK (Norway) proposed research on genetic improvement of Nile tilapia following approaches and technologies pioneered in Norway for genetic improvement of farmed Atlantic salmon (Salmo salar). This proposal was peer reviewed by 25 of the world’s leading fish geneticists. Research and development and dissemination of GIFT was expected to demonstrate potential benefits and returns from using applied genetics in tropical aquaculture.

Nile tilapia was targeted because; (i) it was the most commonly farmed tilapia species in freshwater aquaculture in SE Asia and (ii) generation time was relatively short (~ 6 months), (iii) studies had found that Asian tilapia stocks in general were of poor genetic quality resulting from high inbreeding rates and widespread introgression of genes from undesirable feral O. mossambicus populations. The plan was to develop the GIFT fish using conventional breeding methods, without recourse to gene transfer technologies.

- **Funding and/or revenue model, and degree of commercial viability vs grant reliance**
  The GIFT project was funded by; ADB, the United Nations Development Fund (UNDP), IDRC, Ministry of Foreign Affairs (Norway) and ICLARM. These organizations provided financial support to the project and technical know-how. They participated in consultative meetings prior to the project initiation and regular project reviews, guiding the project as it progressed.

  ADB supported R&D and dissemination of GIFT by providing technical assistance (TA) from 1988 to 1997. Total cost of Genetic Improvement of Tilapia Species in Asia, was $475,000, approved on 8 March 1988 and implemented from 1988 to 1992. The total cost of TA: Dissemination and Evaluation of Genetically Improved Tilapia Species in Asia (DEGITA), was $600,000, approved on 14 December 1993, implemented from 1994 to 1997.

  TA supported an international R&D effort that was coordinated and executed by ICLARM. ADB provided for TA for the first phase of the development of GIFT in 1988–1992 (see above), while UNDP provided $525,000 and ICLARM and its research partners contributed in-kind support. TA for DEGITA was implemented in 1994–1997, funded principally by ADB ($600,000) while ICLARM contributed $302,205 from core funds. In 1993–1997, UNDP provided a further $4,307,690 for a second phase of development of GIFT and related research partnerships and networking, while ICLARM contributed $809,029 from core funds. The national DEGITA program partners (Bangladesh, PRC, Philippines, Thailand, and Vietnam) also contributed in total approximately $300,000 from their national program budgets. Overall, ADB provided $1,075,000 (14.7%) of the combined financial resources of $7,318,924 excluding in-kind contributions made available between 1988 and 1997, Contributions from funding agencies were in the form of parallel financing. The 10-year (1988–1997) R&D evolved over time but was not designed from the outset as a series of predetermined interventions.

- **Operations**
  Detailed plans were formulated by ICLARM, AKVAFORSK, BFAR, FAC and UP-MSI. A series of consultations were held with NARS, advanced scientific institutions and donors that resulted
in a research partnership that took advantage of the strengths of each of the participating institutions, as detailed below:

- ICLARM coordinated the project and provided the initial impetus and technical skills;
- BFAR provided necessary infrastructure facilities while addressing national needs;
- CLSU, Philippines provided researchers and research facilities;
- AKVAFORSK provided academic and technical expertise in applied fish genetics;
- UNDP and ADB provided development know-how, project formulation guidance, project review and funding
- NARS institutions in Egypt, Ghana, Kenya and Senegal provided wild Nile tilapia germplasm, and institutes in the Philippines provided local domesticated, farm strains of Nile tilapia.

- **Marketing**

Dissemination of GIFT was initiated after performance evaluation trials were conducted on-station and in on-farm environments in five INGA member countries (Bangladesh, China, Philippines, Thailand and Vietnam). Improved germplasm was then propagated and disseminated to local farmers via regional NARS institutions. In the Philippines, GIFT Foundation International Incorporated (GFII) took responsibility for dissemination of the GIFT strain following accreditation of local tilapia hatcheries. At this time, infrastructure and competencies that had been established as part of the GIFT project, and the potential for significant commercial gains of the improved strain caught the attention of foreign private companies and stimulated interest in collaboration. The GFII recognised that a formal alliance with a private-sector company would enable it to advance its selective-breeding research, acquire a competitive edge in the commercial market, and improve its overall financial position. In 1999, GFII entered into a formal agreement with GenoMar, a private Norwegian company specialising in bioinformatics tools for selective breeding. The agreement between GenoMar and GFII included:

(i) GFII was provided with shares in GenoMar in exchange for fish from the Foundation’s tilapia-breeding nucleus (‘GIFT Super Tilapia’ Trademark) and other commercial assets
(ii) GenoMar contracted GFII to maintain and breed GenoMar’s tilapia germplasm collection;
(iii) GFII was involved in distribution in the Philippines of seed stock produced from the GenoMar nucleus.

GenoMar took responsibility for R&D activities with GenoMar in Norway finalising breeding models and plans, and instruction was provided to GFII staff to conduct the breeding work in the Philippines, GFII via the agreement with GenoMar received funds to cover the costs of breeding activities and also to maintain an independent breeding nucleus. Revenues generated and genetics research expenditure from 1998 to 2002 ranged from PHP9.92m to PHP16.9m and from PHP9.43 to PHP16.52m, respectively. Dissemination of the improved fish breed (GIFT) was facilitated by INGA/ICLARM. Protocols and quarantine procedures for transfer of germplasm based on International Codes of Practice and Material Transfer Agreement were used as guidelines. In total, 7 Asian and Pacific countries have received improved GIFT fish germplasm.

- **Relationship with hatcheries and grow-out farms**
After formal completion of the GIFT program in 1997, representatives from all GIFT families were made available to INGA member countries and partners interested in follow up breeding work with GIFT. As a result, WorldFish in Malaysia and most INGA member countries received GIFT stock from both the 6th and 8th GIFT generations. During this time participation of the private sector as multipliers increased. At the same time, rights to the GIFT fish were given to GFII to continue the research program and to market the fish. GFII disseminated GIFT via licensing arrangements with privately owned hatcheries in the country with over 200 million fingerlings disseminated in the first 5 years of operation. GFII however, was not wholly successful and to remedy this, GFII entered a collaborative program with GenoMar ASA-a Norwegian private company. GenoMar acquired commercial rights to the GIFT strain and continued with the breeding program and entered into commercial ventures using their trademark name, GenoMar Supreme Tilapia in the Philippines, Brazil and China. The company continued research and development that was later privatised resulting in GST, GET EXCEL products. Research and breeding of GIFT (6th generation onwards) moved with WorldFish Centre to Malaysia in 2002. In Malaysia, the GIFT breeding program has continued the selection for higher live weight at harvest time to improve growth rates. The GIFT strain has since been exposed to seven additional generations of selection in Malaysia.

Since being moved to Malaysia, the GIFT strain has been disseminated to nine countries in Asia and Latin America. The program is now well positioned to consider incorporating new traits in the breeding objectives, especially if the population size is increased. WorldFish scientists however, have stated recently that they now face major challenges with further development of the strain. Methodologies adopted for the GIFT program were later disseminated to developing country NARS through intensive training programs in quantitative genetics and their applications in aquaculture in addition to preparation and distribution of a Manual of Procedures.

E. Technical strategy of the genetic improvement program – including:

- Technical approach to genetic improvement and key processes involved

  Acquiring and assessing Nile Tilapia germplasm for the GIFT program

  Acquisition of Wild Nile Tilapia Germplasm from Africa.

  Between 1988 and 1989, ICLARM and partners collected germplasm from four wild strains of Nile tilapia from across the natural range in northern Africa involving visits to Egypt, Ghana, Kenya, and Senegal. More than 2,000 fish were shipped to quarantine facilities at NFFTC in the Philippines. Collection and shipment of germplasm involved extensive collaboration and coordination with international partners and institutions. Introductions constituted the first direct and well-documented acquisitions of wild tilapia germplasm in Asia since 1962, apart from a single introduction of Nile tilapia from Sudan to China in 1978.


Weights at harvest after 90 days of first generation progeny were compared among the eight Nile tilapia strains. The four Asian farmed strains originated from a widely farmed Israeli strain and three others named after their most recent origins prior to their introduction to the Philippines: Singapore, "Taiwan" (both probably derived from introductions from Israel), and Thailand (probably of Egyptian origin). Fish from the eight strains were tagged (PITs) and stocked communally in 11 different farm environments that included ponds, cages, and rice-fish systems both in lowland and upland locations. This required tagging of 11,000 individual fish and was the largest experiment of its kind ever undertaken in Asia. Three African wild strains (Egypt, Kenya, and Senegal) grew consistently as well as, or faster than, Asian farm strains in all test environments. Results confirmed significant heritability ($h^2$) for growth
performance in all strains. It was also evident in general, in the initial trials that ‘wild’ tilapia grew to larger average weights at harvest than fish descended from Asian stocks that had been farmed for more than 20 years.

Breeding Strategy
From experience with genetic improvement of Atlantic salmon in Norway, Akvaforsk advised ICLARM and its partners that artificial selective breeding (via family selection) offered the best strategy for developing an improved _O. niloticus_ strain for SE Asia. They also suggested exploring potential advantages of crossbreeding (lower cost, less technically-demanding) among the eight assembled genetically-discrete, Nile tilapia strains that resulted in an additional large-scale experiment. Mean weights at harvest (90 days) of all 64 possible pure- and crossbreed lines were measured in different test environments (included ponds, cages lowland and upland locations). In general, hybrid vigour (harvest weight advantage of crossbreeds over parents) was low (averaging only 4.3%) and was significant and positive in only 22 crosses, of which only 7 performed better than the best pure strain. The best crossbred line showed only an 11% harvest mean weight advantage over its parents, so given in general low hybrid vigour, selective breeding was chosen as a better strategy for development of an improved line.

- **Technology used in the development of the genetic improvement program**

  Selective breeding
  To ensure high levels of genetic variation in the founding population for selective breeding, a synthetic base population was developed from the 25 best-performing pure and hybrid stocks of the 64 tested in the crossbreeding trial. 200 tilapia families were then established in breeding _hapas_ (small net cages) by mating 100 selected males with 200 selected females from the synthetic base population. Representative samples of their progeny were tagged, distributed to test environments and grown out for 120 days. Breeders were selected for the next generation using standard quantitative genetics methods. Selection was based on relative performance of both family and individuals within a family.

  **F. Genetic improvement outcomes**
  - **Estimated degree and nature of enhanced performance after the genetic improvement**

  Response to selection
  During the development of GIFT in the Philippines, responses to selection for weight at harvest (% gain over previous generation) over five generations of selection were 19.1%, 13.5%, 9.2%, 17.8%, and 6.2%, respectively, totalling 65.8% after five generations of selection. Please note that critics of the project observed that the synthetic base population itself, before imposition of any selective breeding, showed a 60% advantage in harvest mean weight over local farmed Philippine _O. niloticus_ strains. This was attributed largely to crossbreeding effects during development of the synthetic base population. When this advantage was included with subsequent responses to the selection regime over 5 generations, this represents a claimed growth performance advantage of approximately 125% for GIFT over local Philippine farm strains. So, in comparable environments, GIFT should reach harvest size in less than half the time taken by unimproved local Philippine farm strains. It should be noted however, that subsequent comparisons (including those during DEGITA) of the performance of GIFT vs other Nile tilapia farmed in Asia showed lower growth advantages for GIFT and, in some cases, they were not significant. This most likely resulted from growth comparisons among strains in different production environments. Comparisons can only ever be valid when strain performance is compared in the same production environment (location, time, and farming system). A wide range of differences in performance between GIFT and non-GIFT tilapia in Asia is to be expected, given the extensive history of tilapia translocations in Asia and wide
variation in relative quality of broodstock management, as well as the relative local degree of adaptation of different local tilapia strains. It is particularly important to note that genetically improved strains are developed to perform under specific environmental conditions, so for example, if food quality and/or supply was optimal during strain development but the improved line is later evaluated on low quality/volume diets or in poor water quality, it would not be surprising to see large declines in their relative performance, because improved strains require good production conditions to reach their full genetic potential. Despite complexities of Genotype vs Environment (GXE) interactions, developers of the GIFT strain demonstrated that Family selection could produce progressively faster growing generations that can perform well in a number of production environments, and that application of genetics to tilapia farming, and by inference to tropical aquaculture in general, could produce a highly productive improved Nile tilapia farm strain over a 5-10 year stock improvement program.

- **Other outcomes**

The most significant outcome of GIFT development and dissemination in the Philippines has been the successful application of genetics to the breeding of new and better performing strains of farmed tilapia and their effective dissemination. Socioeconomic impacts are evident in the extent of use of GIFT and GIFT-derived strains that comprise close to 70% of the tilapia seed now produced in local hatcheries. Increased availability and affordability of fish protein for local consumers as well as generating employment opportunities and income improvement for tilapia farmers, workers, and various market intermediaries were also major benefits resulting from the program. Indicative net returns for tilapia hatcheries and farms in the Philippines and Thailand. Are described in an Asian Development Bank report *(ADB. 2004 entitled: ‘Special Evaluation Study on Small-Scale Freshwater Rural Aquaculture Development for Poverty Reduction’. Manila.* For GIFT hatcheries, net returns are approximately USD$5,000/hectare (ha)/year. For GIFT grow out ponds, excluding fish consumed by households on the farms, net returns range widely, from USD$1,783 to $4,241/ha/crop cycle, due to variation in the duration of the crop cycle, production costs, and farm gate prices of tilapia. Crop cycles differ according to desired fish size at harvest: 8 months for relatively large fish (500–1,000 g/fish) and 4 months for smaller fish (up to about 250 g/fish). In the Philippines, 4-month crop cycles, allowing two crops a year to fit climatic and seasonal conditions, are common. In some parts of central and northern Thailand, tilapia farmers employ 8-month crop cycles once a year or 6-month crop cycles twice per year.

Farmed tilapia (GIFT strain) is now the most important food fish of poor consumers in the Philippines, and has also become an international commodity.

Notable institutional impacts include: improvements in national research capacity, the GIFT-based Philippine national tilapia breeding program, collaborative mechanisms for bringing together tilapia stakeholders (Tilapia Science Center, Tilapia Congresses, etc.), and related public-private sector partnerships. Impact and sustainability of rapidly evolving institutional arrangements will depend primarily on prospects for strong, long-term growth of tilapia farming. Prospects however, are good as indicated by Philippine government endorsement of farmed tilapia as a major contributor to the national economy and as a fish of special significance for local poor consumers. A further indication of the prominent international position held by the Philippines in tilapia farming and associated R&D in the Philippines’ was hosting of the Sixth International Symposium on Tilapia in Aquaculture in Manila, 12–16 September 2004.

While genetic improvement programs for tilapia appear prominently in programs emerging under new institutional arrangements, success will depend on how farmers cope with new
technologies and on the cover and quality of extension services. Aquaculture extension services in the Philippines have traditionally been the responsibility of government and the public sector, mainly through BFAR and state universities and colleges. There are now however, strong indications that farmer-to-farmer networking and technical advisory services from suppliers of fish seed, feed, agrochemicals, and equipment have recently become more important and effective than the traditional extension vehicles. Tilapia farming in the Philippines has changed significantly after application of genetics-based technologies and has entered a phase of rapid growth with increasing private sector participation in R&D and provision of technical advice. Accredited private hatchery operators who receive improved tilapia broodstock are now required to undergo training on genetic aspects of broodstock management and hatchery operation. These developments have resulted largely from the development and dissemination of GIFT and GIFT-derived strains by WorldFish.

G. Lessons learned and implications

- Critical success (or failure) factors/strength and weakness of GIFT program structure

The GIFT Project commenced in 1988 with a base population formed from a complete diallele cross between eight Nile Tilapia strains. The base population contained relatively high levels of genetic variation and inbreeding level was closely controlled with strong selection practiced except for Generation 1. In each generation, >100 families were produced while avoiding mating of close relatives. During the testing period, efforts were made to standardize environmental conditions. These were key elements that led to a very successful project.

Selection response for growth rate over five generations averaged 13.2% and this rate is similar to results obtained in several fish species elsewhere. Results showed that it was possible to double tilapia growth rate over ~six generations, since genetic gain is cumulative across generations. When these results reached local farm industries they resulted in a big change to production levels and productivity with a dramatic reduction in turnover rate and increased levels of production per unit. Feed conversion ratio was also much lower (specific data on how much lower was not reported). Increase in strain productivity was also linked to an increase in survival rate. In summary, production costs were significantly reduced and total production levels increased. Importantly, benefits gained were available to both poor and wealthy farmers.

Cooperation among partners in the GIFT project - ICLARM, AKVAFORSK, and Philippine institutions, BFAR and CLSU was very productive and also impacted technical and educational skill levels.

Risks to Maintaining and Increasing Benefits from Tilapia Genetic Improvement.

There are risks to maintaining and increasing the benefits that tilapia genetic improvement has brought to the Philippines. Most risks are common to all farming and food production systems; for example, climatic uncertainties and changing economic circumstances with respect to the cost of inputs for farming and the relative availability and prices of competitive products. Tilapia breeding and farming in particular, are especially vulnerable to disease and parasite issues when quarantine practices are poor or not practiced at all, fish introductions are not controlled, and/or poor husbandry is practiced. Addressing these multiple and interrelated risks requires strong policies and support to sustain institutional advances that have come from tilapia genetic improvement. In particular, policy gaps need to be addressed and areas of biosafety, gene banking, and seed certification require attention.
The GIFT project developed an improved strain of Nile tilapia in the Philippines that later became the product used to establish the GFII, which now runs a commercial breeding program for *O. niloticus* in the Philippines. GFII built on development of the GIFT strain and continues the selection program to improve growth and survival rates and has extended the QTL focus to improving late maturation. The program is located in facilities built by the government at Munoz, Nueva Ecija, and the Foundation has accredited eight private hatcheries for production of fry for the national industry.

This is a good example of how breed improvement projects can evolve into breeding programs run by private companies that benefit industry. The most difficult aspects of the program were; (i) establishing a breeding organization; (ii) raising sufficient financial support for investment in, and starting, the breeding program; and (iii) raising financial support to scale up production and to market improved product.

- **Implications for a potential EA genetic improvement program**

Applied genetics in aquaculture is a relatively new strategic endeavor, particularly in many developing countries so local capacity to participate in both the technical and academic aspects of such programs is often initially, very limited. Experience indicates that these programs benefit significantly from collaboration among institutions particularly those with past experience in such programs (often offshore) that can contribute to capacity building in both technical and academic areas. Members and associate members of INGA played both direct and indirect active and important roles in various aspects of the GIFT program and in supporting network activities. Close collaboration among network members was particularly evident in the exchange of germplasm following material transfer agreements, effective quarantine protocols and collaborative research projects that were developed during the project. At the end of the first stages of the project, technical and academic capacity to undertake further work in particular in the Philippines was enhanced.

Of note, initial research and technical staff and managers running the project for ICLARM were drawn from diverse backgrounds that included both NGO and technical/academic institutions, that were linked to government and academic research institutes and their staff in the Philippines. Later, once the program had been completed, control for programs involving dissemination of GIFT strain to other regional partners and management of similar programs was under the control of WorldFish Centre. Two scientists (both trained Quantitative Geneticists (Dr Raoul Ponzoni and Dr Nguyen Hong Nguyen) with extensive experience in both terrestrial and aquatic stock improvement theory and practice) were major players that contributed to success of this stage of the GIFT program and related projects (in Asia and Africa) at WorldFish. Over the last ~10 years both have left WorldFish, (one retired and one now has an academic position in Australia). While their replacements at WorldFish are excellent scientists (Dr John Benzie and Dr. Curtis Lind), they bring different skills sets and perhaps different skill foci that have probably not resulted in the same direct engagement in aquatic stock improvement across the region.

**Impacts of GIFT on Biodiversity and the Environment**

Introductions of Nile tilapia for development of GIFT and the subsequent nationwide dissemination of GIFT and GIFT-derived strains are unlikely to have caused any significant impacts on the natural environment and biodiversity, additional to those already made by earlier tilapia introductions. The introductions of Mozambique tilapia (*O. mossambicus*) and Nile tilapia (*O. niloticus*) to the Philippines in 1950 and the 1970s, respectively, resulted in their establishment as alien species in open waters. *O. mossambicus* has been problematic in
the Philippines and in many other countries outside of its natural range. This however, has not been the case for *O. niloticus* introductions, with virtually no negative environmental impacts recorded to date at least for this species. Biodiversity and environmental quality of inland waters in the Philippines have been seriously degraded by many factors, including overfishing, pollution, siltation, and water diversion, as well as introductions of alien species for aquaculture. Potential impacts of Nile tilapia in natural Philippine lakes are difficult to assess because many factors have already contributed to their degradation. During development of GIFT, precautions and prior appraisal of possible impacts of tilapia dissemination and escapes into new water bodies were provided to appropriate agencies.

Introductions of Nile tilapia from Africa for development of GIFT were made under highly precautionary policies by ICLARM. All founder stocks introduced directly from Africa were subjected to strict quarantine for 3–7 months in a completely isolated facility at NFFTC, established in consultation with the BFAR Fish Health Unit and the IDRC of Canada. As a member of INGA, the Philippines followed INGA’s voluntary protocols for responsible movement of fish germplasm. Philippine national regulations on fish quarantine and biosafety were also extensive. Capacity of national agencies including BFAR however, to enforce regulations was limited. This placed at risk not only wild biodiversity and the natural environment but also the biodiversity and genetic resources already available to Philippine aquaculture. Many who introduce and distribute alien species and farmed aquatic organisms, including aquarists, fish farmers, and some researchers, fail to adhere to regulations. A survey during DEGITA found that 84% of Philippine tilapia farmers believed that tilapia do not displace native fish species. A major and long-term effort is still required to educate public and private actors to follow more responsible behaviors with respect to fish movements and quarantine.

Since the 1980s, BFAR has released millions of Nile tilapia seed annually into open waters to improve inland fisheries in communal waters or as contributions to public relief measures following severe typhoons and other disasters. GIFT-derived strains have largely replaced local strains used before the development of GIFT. Refer to Akosombo section for relevance of introducing GIFT to EA or Africa.

### 3.2 Akvaforsk Salmon genetic improvement

#### A. Objectives of the genetic improvement program

One of the main objectives of the Institute of Aquaculture Research of Norway, Ltd. (Akvaforsk) since its establishment in 1971 has been to study the theoretical, biological and practical bases to initiate, develop and run animal breed improvement programs. Their work on aquatic species was initiated on stock improvement of Atlantic salmon and Rainbow trout in Norway. These programs were later transferred to a private breeding company, Aqua Gen that today supplies 70% of farms in Norway with improved eyed-eggs. Akvaforsk has continued to offer expertise and experience in developing breeding programs to members of INGA since the 1990s as well as to others. Services are currently provided through the Akvaforsk Genetics Center.

#### B. Location and geographic scope of the program

Main activities are in Norway with research and development focused on cold-water species including; Atlantic salmon, Rainbow trout, Atlantic Cod and Atlantic halibut, with additional new programs being developed on edible oysters and scallops. Internationally, Akvaforsk
since 1970 has also been engaged in salmon genetic improvement in many countries in Europe, SE Asia and South America. Projects are primarily in the fields of stock improvement via selective breeding and nutrition work.

Akvaforsk is a non-profit research institute owned by public shareholders. (Note: Akvaforsk Genetics Centre – a subsidiary of Akvaforsk was established to undertake development work and consultancies. It was sold when Akvaforsk merged with Nofima. It is now called Akvaforsk Genetics and is owned by Benchmark Holding). The main office is located at the Agricultural University of Norway (AUN), 30 km south of the national capital, Oslo. They also have two research stations at Sunndalsøra and Averøy located in coastal areas ~500 km northwest of Oslo. The Institute has ~85 employees, of whom 28 are scientists and some are Ph.D. students. AKVAFORSK scientists also teach aquaculture sciences at AUN and at Sunndalsøra College. The institute has actively promoted the importance of maintaining strong engagement between academic and technical/production areas, so that research results and developments in programs can be translated directly to broader industry outcomes. In part, this involves capacity building by the institute via postgraduate training and supervision.

C. Relevant wider aquaculture industry dynamics relating to the program

Atlantic salmon is one of the world’s leading farmed aquatic species in terms of; control of the production process, sophistication of supply chains and product quality. Atlantic salmon is also the most commonly farmed salmonid, and its share of world production has been increasing. Substantial quantities of other farmed salmonids come from Coho salmon and Rainbow trout, while relative quantities of other farmed salmonids for example, Chinook salmon are much smaller. Global production of farmed salmon exceeded 3.4 million metric tons (mt) in 2014. While this only represents 4.7% of total world aquaculture production volume, it accounted for >12.9% of total production value, making salmon the second most valuable farmed aquatic species after marine shrimp.

Feed conversion ratio in salmon aquaculture has also been decreased significantly in conjunction with the stock improvement program. In the 1980s, to produce 1 kg of farmed salmon required more than 3kgs of feed, while today, in combination with improved feed composition, the most experienced farmers are able to produce 1 kg of fish from slightly over 1 kg of feed. Composition of feed has also been improved from in-house mixes of lower quality marine fish by-catch and waste from food processing plants, to development of highly knowledge-based feeds produced by specialized companies. An initial tipping point came in 1982, when dry pellet feed was introduced. Salmon farming remained however, highly dependent on the quality of marine ingredients included in feeds because they form the basis for fish flesh pigmentation as well as a primary source of Omega-3 oils. From the late 1990s, improved nutritional knowledge has allowed a higher percentage of vegetable based ingredients to be substituted into dry-pellet feeds that has reduced dependence on marine animal ingredient sources and so, reduced feed costs significantly. Since feed costs for Atlantic salmon can account for ~60 or 70% of total production costs, this development has had a major impact on expansion and sustainability of the salmon farming industry. This approach has also reduced production costs and efficiency in many other farmed aquatic species.

Grow-out of salmon takes place in sea pens, a practice that has not changed since 1969. Technological innovation has, on the other hand, allowed farmers to produce smolts in closed, land-based highly controlled environments instead of in open-pond systems, and currently there is substantial research interest in trialing land-based grow-out facilities. Over time, improvements in pen design, pen size and use of automatic feeders has enabled the scale of
many production plants to be increased substantially. As a consequence, production has grown from 100mt/yr to >5000 mt/yr. In 1980, Norwegian salmon sea pens were 5 m diameter X 4 m depth, while in 2013 measurements had been expanded to 70m X 45 m, respectively. This has also led to better capacity utilization. Between 1986 and 1998, despite a significant reduction in the real price of feed, relative feed cost share went from 27% to 50%. Increasing feed cost share is a signal that all remaining cost-contributing factors are becoming more efficient. Today, the cost share of feed exceeds 55%.

In the 1980s, disease created substantial challenges for development of the farmed salmon industry as densities of fish in cages were higher than in the wild, facilitating disease transmission. At first, the only tool available to keep pathogenic bacteria in cages under control was to apply antibiotics administered through medicated baths or in feed. As veterinary knowledge of fish diseases has expanded, antibiotic use has been reduced to almost zero. In part, this has been achieved by improved management systems with the focus moving towards preventative vaccination rather than post-infection treatment. Diseases and parasites however, still continue to pose challenges for the industry. For example, an outbreak of infectious salmon anaemia resulted in Atlantic salmon production declining by two thirds in Chile in 2009. Salmon lice however, are currently considered to be the most serious infection problem facing the farmed salmon industry and research is actively being conducted to find ways of containing and/or eradicating this parasite.

By the 1980s, production had increased sufficiently to allow for investment in small, specialized slaughtering facilities mostly on farm, where the fish were gutted, bled and filleted by hand. In the 1990s, the salmon industry began moving to less-wasteful production processes following development of specialized harvesting systems and productive uses were also found for trimmings and cut-offs. The salmon industry today has access to advanced equipment and systems for all stages across the value-chain, from gutting and weighing, to filleting, skinning, deboning and portioning. Large processing plants have also facilitated a move from labour intensive production to more capital-intensive autonomous production. Larger processing plants can now handle ~6500 fish per hour. Despite significant advances in processing, processing speed is still affected by the number of manual interventions required, as well as by steps that involve use of large refrigerated saltwater tanks to maintain low temperature inside fish during processing.

Transport over long distances was facilitated by the development of leak-proof polystyrene foam packaging that has gradually facilitated expansion to a global market. Opportunities to expand markets were linked to packaging innovation and airfreight in particular, when the USA and Asia became significant markets in the mid-1980s. For example, transport cost per kg of frozen salmon from Chile to any part of the world is now ~0.50 USD. This development allowed producers regardless of location to access world markets and distribute a variety of products at relative low cost.

D. **Overall business model and funding – including, where possible:**

- **Overall structure, approach and organizations involved**
  There are three milestones in the organization of the Norwegian salmon-farming industry (NSFI). In 1969 the net-pen production technology was established, and formed the basis for all further organization. In 1978, the Fish-Farmers Sales Organization (FSO) was established, and the organizational and institutional apparatus were thus complete. In 1991 the FSO went bankrupt and major amendments to aquaculture legislation – such as removal of the ownership regulation – were made. More detailed information on this
three-step development is analysed along with approaches used and other associated information in sections below.

Of specific importance are the effect of dislocation of decision control from the local level to remote actors, and the changes in the Norwegian government’s aquaculture policy. During the years the NSFI has changed from a single farm locally-owned industry to a structure of large corporations, while the governments’ policy has changed from direct industry support to more neutral tasks including industry control and surveillance. In sum, local residents use rights of coastal areas has been severely reduced.

The organizations involved includes;
- AKVAFORSK- NOFIMA marin
- Norwegian Agriculture College
- Norwegian aquaculture Association
- Aquaculture Sales group AS
- Norwegian Aquaculture Station AS
- Norwegian Salmon Breeding AS
- AquaGen: Sunndal, Hemnes As and Norway
- Team Semin As
- Geno As

- **Value proposition**

  Commercial production of salmon for human consumption first started in the late 1960s in Norway when smolts were placed into sea cages by the company Mowi A/S in Bergen in 1969 and by the Grøntvedt brothers on Hitra in 1970. Since pioneering days in the early 1970s, rapid and almost continual growth has meant that this industry has now achieved status as one of the world’s most economically important industries within the fisheries and aquaculture sectors. In 2014, global production of salmon exceeded 2.3 million tons with Norway (1.26 million tons), Chile (0.62 million tons) and the UK (0.165 million tons) representing the primary producers. In total, 10 countries produced more than 10,000 tons in 2014. The salmon genetic improvement program adapted to industry demands as it grew, with individual growth rate the initial trait improved.

  Globally, production of farmed salmon was rated as number eight by amount for aquaculture fish species, and was by far, the most valuable cultured fish species in 2014 (14.6 billion USD). Today, more than 99% of all salmon consumption arises from aquaculture production, and the reported wild catch is as low as 1/1000 of the reported aquaculture production. As a form of food production, aquaculture is increasingly being considered as a major solution to the world’s growing demand for protein, although not all share this optimism. Nevertheless, commercial aquaculture, including salmon farming, continues to expand globally.

**Funding and/or revenue model, and degree of commercial viability vs grant reliance**

As the industry developed in the 1980s, due to rigid managerial requirements, the Norwegian government added responsibility for provision of research, education and extension work. The government also channeled substantial resources to streamline the industry. A research and development program, educational program, a financing program, fishery extension service, and a system of business advisors, in addition to considerable administrative resources, were made available and paid for by the government. The Norwegian Aquaculture Act was rigidly enforced by the Ministry of Fisheries and environmental and agriculture departments cooperated as a result of requirements included in the legislation to address issues that included aquatic pollution and fish health. The Fishery legislation made the NSFI
strong, rigid and monolithic, and put NSFI safely within the framework of the Local Decision Control Model.

By the end of the 1970s, NSFI provided organized market access, a simple and effective technology, a capable administrative system, a standardized body of knowledge, good farming locations and many motivated and skilled producers. Due to the fact that NSFI was a well-organized industry in the early 1980s, the local banking system was generally enthusiastic about its progress and prospects and fueled development financially. The specialist salmon farmer was ‘created’, the salmon farming industry was organized, and the government was genuinely supportive. While production was still relatively modest FSO could safely operate with a minimum price in a market that increased in scale. One-third of the budget (Akvaforsk) is basic funding from the Research Council of Norway, and most of the remainder comes from competitive-grant research projects.

- **Operations**
  Essentially knowledge and skills on applied genetics and breeding strategies developed earlier on livestock species in Norway were translated to, and modified for, aquatic species that generally have complex life histories very different to those present in livestock species. Harald Skjervold at the Institute for Domestic Animal Breeding, NLH was the driving force that introduced modern principles into Norwegian domestic animal breeding. In 1970 he was granted permission to capture genetic strains of Atlantic salmon and to establish a selective breeding program for Atlantic salmon. Trygve Gjedrem, at the Institute for Domestic Animal Breeding, NLH took on the responsibility for applied genetics research on the target aquatic species. Their work has encouraged many modern breeding programs on aquatic species in Europe where now 80 to 83% of aquaculture production originates from improved farm lines mainly explained by the dominance of salmon farming in European aquaculture and the high combined market share of salmon breeding companies (93–95%).

  Currently, there are an estimated 37 aquatic stock improvement programs in Europe of which the majority apply family selection methodologies. While cumulative genetic gains in growth performance vary with program, efficient and well-designed stock improvement programs have had, and will continue to have, a major impact on development of European aquaculture and it is highly likely that in the future all famed aquatic species across the region will rely on improved culture stocks.

- **Marketing**
  The general impact of selective breeding on European aquaculture, and in particular Atlantic salmon farming is evidenced by the combined market share that breeding companies have on total production levels, the number of traits that have been improved and the cumulative genetic gains achieved. Prior to the 1970s, salmon primarily wild caught, was supplied to European high-end markets as a luxury product with large seasonal supply variation. Market expansion occurred from 1969 with the introduction of large net pens, a change that has smoothed out supply variation and gradually this development has also increased supply at lower cost.

  Closing the entire natural production cycle in captivity in the early days of salmon farming has allowed systematic R&D efforts to be directed at all stages of the supply chain. R&D has resulted in innovations that have led to substantial productivity growth that has reduced real production costs by greater than two thirds. Production gains have been passed onto consumers as lower prices, while the industry has benefited from increased competitiveness, higher quantities of product and increased market share. There is a large literature base
available that documents how production costs have declined significantly over time and lower production costs and price has enabled farmed salmon to become competitive in new markets first geographically, as the market became global, and increasingly thereafter via product development. The main factor to reduce production costs and productivity is to improve growth rate by applying improved technologies and better production practices. An actual or real decline in Norwegian productions costs and export prices has been reported since 1985, i.e., both production costs and export prices have shown clear downward trends since 1985. For example, the average real export price in 2008 was 30% of the price in 1985 and production cost was 28% of the cost in 1985. Feed accounted for 54% of operating costs in 2008 and this is the only component for which the share (of feed cost) increased from 34% in 1985. While this indicates an increase, the actual cost of feed reduced (11 NOK/kg in 1985 to 9.76 NOK/kg in 1994). This also indicates that other inputs are being used more efficiently. The cost share of smolts has been reduced from 25% in 1985 to 12% in 2008. Similarly the share for capital (depreciation and financial costs) has been reduced from 12% to 8%, labor from 15% to 9%, insurance from 4% to 1%, while other costs have remained steady at 12%. It should be noted that the production process has become more capital intensive as feeding and other processes have been automated. (Source: Asche, F and Bjorndal, T. 2011. The Economics of Salmon Aquaculture). The industry now produces a variety of different processed products, with smoked salmon being the most notable given its gain in market share. Development of value-added products however, has been relatively limited in scale.

The first Atlantic salmon egg cohort selected for improved growth rate were produced at Akvaforsk AS in 1975 while the first egg cohort selected for late sexual maturation were produced in 1981. Following these developments, annual meetings of the Norwegian Aquaculture Association and the Aquaculture Sales group AL in 1985 voted to start an organised system of selective breeding and egg sales. This led to the Norwegian Aquacultures Breeding Station AS being built at Kyrksæterøra. In 1986, a copy of all Atlantic salmon and Rainbow trout families held by Akvaforsk AS were transferred at no cost to the Norwegian Aquacultures Breeding Station AS. Transfers then occurred every year until the generational intervals of Atlantic salmon and Rainbow trout were fully covered. The same genetic material is maintained at both breeding stations (Sunnidaløra and Kyrksæterøra). Thereafter followed production and marketing of improved eggs from the Norwegian Aquacultures Breeding station AS to producers.

In 1987, the first groups of smolt from the breeding stations at Kyrksæterøra and Sunndalsøra were transferred to external commercial fish/egg producers. All of the egg producers in the selective breeding system now had improved material from the breeding stations. In 1982, the Norwegian Aquaculture Breeding Station AS entered negotiations after the bankruptcy of Aquaculture Sales Group AL in 1992 and the Norwegian Salmon Breeding AS was established. Norwegian Aquaculture Association at this time was the sole shareholder but later, Norwegian Salmon Breeding AS took over Norwegian Aquaculture Breeding Station AS shares in the company.

Fresh, frozen, and smoked salmon together now account for more than 85% of product share in France. Increases in cost and requirement for producing processed product has also led to the development of higher-value cuts including loins (the same occurred with chicken fillets), as well as some niche market products based on ‘nuggets’, trimmings and cut-offs. To date however, product development in general has been limited in scale and whole or filleted salmon, whether fresh, frozen or smoked, remain the major market products. Very recently, some smaller markets have been developed for the waste that results from salmon.
processing. For example, post-2000 a market was created for fish heads, while in Norway, approximately 35% of live fish weight that is converted to fillets represents trimmings and offal and much of this otherwise waste material, is now reduced to new products including; fish oil, fishmeal, or silage.

Over time, the Atlantic salmon aquaculture industry has been moving away from the organization model found commonly in traditional fisheries. Small companies that used to operate in a single location have evolved into larger companies that operate at multiple locations supported by other sectors. Over the last decade, the industry has begun on a path to integrate vertically, as well as horizontally, by creating large companies that own both production farms and processing operations and as processing operations have increased in scale, their number has declined. So in general, the industry overall has expanded and diversified greatly but there are now fewer, but much larger commercial operators.

Basically, two types of producer companies can be distinguished in Norway. The first type controls the entire process from reproduction to harvest and has integrated an ongoing stock improvement program into their production process. The second more specialized type of breed improvement company operates a breeding program as its core activity that operate in an international market producing improved eggs/juveniles for sale to grow out producers. There is a high degree of competition in this market because most salmon breeding companies belong to the second specialized type.

At an early stage in development of the salmon industry, research revealed that selection at the family level was a better option than the more simple mass selection approach, so now the vast majority of specialized breeding companies are based on family selection. Modern integrated companies employ both mass and family selection about equally often but where mass selection is used, selected traits are generally limited to growth performance and some specific morphological traits, while family selection programs often include additional QTLs.

• **Relationship with hatcheries and grow-out farms**

Specialized breeding companies now play a dominant role in salmon farming. In part, this may be explained by the way that genetically improved germplasm is distributed with salmonid eggs easily disinfected and shipped over long distances.

The number of breeding companies in Europe that focus on salmon is high compared to other farmed fish species when volume of fish production and combined market share of breeding companies are taken into account. Breeding programs integrated with production can coexist relatively easily with other direct competitors, because their existence depends on overall performance of the company as opposed directly to results obtained from the breeding program itself. This may explain why there are relatively few breed improvement companies for farmed Mediterranean fish species. The larger number of breeding companies producing salmon rather than trout can be explained by the uniformity of the salmon farming industry contrasted with a highly diverse trout farming industry. Uniformity within the salmon farming industry allows benchmarking with breeding companies often focussing selection on the same traits. Diversity in the trout farming industry complicates benchmarking with breeding companies often selecting for different traits. Looking towards the future, for salmonids further concentration of breeding companies is the expectation. This trend has already taken place for industrialised livestock species and is being repeated in the salmon industry recently with more mergers of companies occurring producing larger and fewer numbers of producers.
E. Technical strategy of the genetic improvement program – including:

- Technical approach to genetic improvement and key processes involved

Atlantic salmon are anadromous (lifecycle involves reproduction and juvenile development in freshwater and a feeding stage and maturation in the marine environment) and early research was successful in mimicking the salmon's natural reproductive cycle with production consisting of three main stages: egg production, smolt production and juvenile grow out. Closing the complete natural cycle in captivity in the early days of salmon farming has allowed systematic R&D efforts to be directed at all stages of the supply chain. R&D has resulted in innovations that have led to substantial productivity growth that has reduced real production costs by >66%. While detailed breakdown in numbers is not available, production costs have been reduced due to better fish as a result of vaccines, medicines and selective breeding. Better feeds have been developed with substitution employed to reduce amount of expensive marine ingredients. Better technologies have also been developed, for example 2 kg harvest per juvenile fish released in 1987, compared with 4 kg in 2014. Source: http://fishpool.eu/wp-content/uploads/2016/10/Dag-Sletmo-Norwegian-salmon-farming-del-2.pdf. A large literature base is available that documents how production costs have declined significantly over time.

In the 1970s, AKVAFORSK developed the theoretical basis for breeding programs for Atlantic salmon and Rainbow trout that were outcomes of a series of research projects. The program started and developed in Norway as follows. In 1971, the breeding station at Sunndalsøra collected Atlantic salmon from twelve Norwegian salmon rivers. This formed the basis for the first cohort of salmon used in selective breeding. Each year, over the following three years (1973, 1974 and 1975), salmon were collected from a total of 40 Norwegian and a single Swedish river. This produced four independent base population cohorts that now cover the complete salmon generational interval (4 year growth cycle) so that from this time each year, a new generation of Atlantic salmon is produced in the form of fertilized eggs.

In 1992, Akvaforsk invited the industry to participate in running the program (private sector simply received the improved smolts and then provided data – relative productivity in culture relative to previous generation, back to Akvaforsk), and a breeding company, Aqua Gen, was established. From that time until now, Aqua Gen has run the national breeding programs for salmon and trout in Norway. In 1993, capital holdings of Norwegian Salmon Breeding AS were expanded. Owners from the industry, government, bank/insurance and equipment providers came in as partners and Norwegian Salmon Breeding AS took over AkvaGen AS, shares (Akvaforsk AS’ company for the production and sale of eggs) at Sunndalsøra. In 1994, the first Atlantic salmon eggs selected for improved fillet colour were developed and sold while in 1995, the first Atlantic salmon eggs selected for disease resistance were developed and body fat and fat distribution were identified as new key QTLs and integrated into the breeding goals. In 2004, the breeding program celebrated its 10th anniversary.

A collaborative project in the same year, conducted by Team Semin AS and later Geno AS developed the technique for freezing milt and this internationally pioneering technique made it possible to better exploit the genetics of high-performing male fish in the breeding program. Frozen milt from the four cohort populations were then combined to produce a larger breeding nucleus. Elite eggs are now taken from the breeding nucleus every year and transferred to all external breeding fish/egg producers as the basis for commercial egg production. In addition, a patent was granted for the chromosomal area on the Atlantic salmon genome that codes for Major Histocompatibility proteins (MHC) involved in immune
defence and that contribute to resistance against important viral diseases in both Atlantic salmon and Rainbow trout.

In 2005, the main AquaGen office moved from Kyrksæterøra to Trondheim and AquaGen Sunndal AS and AquaGen Hemne AS were combined to form AquaGen Norway A. Sunndalsøra (AquaGen Sunndal AS) was closed as a production location for eggs and fry, after having produced eggs for the industry since the 1970’s. To improve production levels and efficiency, capacity was moved to Tingvoll and Kyrksæterøra. In 2007, a gene mutation that controls Atlantic salmon resistance to IPN was bred into Aqua Gen brood fish to produce a resistant, robust line. In the same year, previous selection methods that were based on average performance of families were modified to also include the best candidates within families (within/between family selection) with individuals identified directly via DNA-analysis. In 2009, the first salmon eggs selected based on gene markers associated with resistance against the IPN viral disease (Marker Assisted Selection – MAS) were launched and in 2013, AquaGen changed the company logo to one that stressed the association between breeding and genetics in fish.

Currently, AquaGen operates a large selective breeding program that systematically measures 22 QTLs in Atlantic salmon and 12 QTLs in Rainbow trout. By measuring and maintaining control over many important traits, they achieve a strong basis for maximising genetic gains while minimising minimal impacts of inbreeding. Traits that are included in the program are categorized as either ‘effective’ or ‘robust’. ‘Effective’ traits are of a production-technical and qualitative character type while ‘robust’ traits affect health and animal welfare characters. Akvaforsk has contributed further to development of the breeding program by including new economically important traits, optimizing the different components of the program and continuously estimating individual and family breeding values (EBVs).

- **Technology used in the development of the genetic improvement program**
  First attempts at genetic improvement of salmon were based on simple mass selection approaches, but as the industry matured more advanced breeding practices in particular, family selection became the preferred option.

Initially, Akvaforsk collected wild fish from 40 Norwegian rivers and a single Swedish river, and the original Mowi farm strain to establish the breeding program from which the current AquaGen strain originated. Other strains with major contributions to currently farmed salmon in Europe include the Bolaks, collected ~1974-1975, and Jakta, collected in the 1980’s. For Atlantic salmon, the total number of selected generations has reached approximately 10, of which 4 to 11 generations have applied family selection. With the exception of the AquaGen program, all started with mass selection. From 2000, family selection became the method of choice. A common garden experiment that compared performance of the Mowi strain selected for 7 to 8 generations with a wild strain of similar origin showed that the Mowi strain were on average 121 to 131% heavier over the same growing period and Thermal Growth Coefficient (TGC), calculated from their data, was 42 to 48% higher. For 7 to 8 generations, these estimates correspond with a selection response of 11 to 12% at harvest weight or ~5% for TGC. Another experiment that compared juveniles of the Mowi strain selected for 9 to 10 generations with a wild strain showed that the Mowi strain were 196% heavier when exposed to identical production conditions over the same growing period and TGC was 83% higher. Over 9 to 10 generations, these figures correspond with a selection response of 12% for harvest weight or 6.6% for TGC. Assuming similar selection responses in other breeding programs, 10 selected generations can produce a cumulative genetic gain of more than 200% for harvest weight and 80%+ for TGC. Genetic gains achieved in the programs reduced growing
period from 4 to 2 to 3 years from egg to harvest and an increase in average harvest weight to approximately 5 kg.

F. Genetic improvement outcomes

- Estimated degree and nature of enhanced performance after the genetic improvement
  
  From the 1970s to 2010, genetic improvement of Atlantic salmon have contributed to;

  - a reduction in production time in freshwater (egg to smolt) from 16 to 8 months and in seawater (smolt to harvest size) from 24 to 12 months
  - a significant increase in mean age at sexual maturation (provides more time for growth before energy is converted into reproduction)
  - more efficient use of feed as less feed is required per kilo of meat produced
  - survival rate is higher, in part because resistance to important viral diseases such as IPN has increased
  - fillet quality (fat and colour) has been improved

By the end of 2017, at AquaGen - all broodstock undergo traditional family selection based on information collected for more than 20 measured traits. After the best broodstock candidates have been selected, where growth traits receive extra weighting, samples are taken for DNA analysis and genotyped for specific genetic markers (QTLs) associated with different performance traits. Genomic selection means that thousands of genetic markers are used to achieve desired characteristics in selected breeders. As a consequence, AquaGen has made great achievements in QTL and genomic selection that deliver salmon eggs with the following traits:

**QTL-selection gives protection against:**

- **IPN:** Infectious Pancreatic Necrosis (QTL-innOva® IPN)
- **LICE:** *Lepeophtheirus salmonis* (QTL-innOva® LICE). “Lice collecting fish” will not be used for reproduction.
- **PD:** Pancreatic Disease (QTL-innOva® PD)
- **CMS:** Cardio Myopathy Syndrome (QTL-innOva® CMS)
- **HSMI:** Heart and skeletal muscle inflammation (QTL-innOva® HSMI)

**QTL-selection gives improved performance for:** **RED:** Strong and even fillet colour (QTL-innOva® RED). This trait can be chosen in addition to all three main products; QTL-innOva® PRIME, QTL-innOva® SHIELD og GEN-innOva® GAIN.

**Genomic selection gives protection against:**

- **2G LICE:** 2 generations of genomic selection against lice (55 000 gene markers are used)
- **1G AGD:** 1 generation of genomic selection against AGD

**Genomic selection gives extra progress for:**

- **2G GROWTH:** 2 generations of genomic selection for growth

**Additional treatment of brood fish and eggs**
After the egg type is selected, a number of treatments of brood fish/eggs can be chosen. In addition, operational practices have been improved, knowledge and experience about the best ways to grow salmon have been improved, and vaccines against important diseases have been developed. All have contributed to the generally positive results.

G. Lessons learned and implications

- Critical success (or failure) factors/Strengths and weaknesses

While the Atlantic salmon stock improvement program in Norway has made significant progress since it began in the 1970s, there is still significant potential for ongoing development. Key factors contributing to success of the farmed salmon industry include; efficiency and strong focus on reducing time between production and delivery to customers and improving capacity utilization. In parallel, processing technologies and supply chain development have progressed, factors that were also important in the early development stages of the broiler chicken industry. Substantial improvement has also been made across the supply chain from pre-slaughter to post-slaughter and with transport systems to a stage where it is now possible to process up to ~ 6500 fish/hr.

In the salmon industry, most processing steps have remained largely unchanged and were only semi-automated from the late 1990s. This has meant that cut and weight of fillets produced will fluctuate, indicating that the industry has not yet reached a comparable level of efficiency as with chicken processing. High variation in harvested fish size makes it difficult for machinery to be developed that can produce a homogeneous product. Being able to process fish into consistent, reliable fillet products would increase predictability in the supply chain and allow producers to innovate with respect to value-added products, would create new opportunities for processing industries to emerge, and would provide customers with clear standards. The processors would, as a result, have the opportunity to further increase the value of the fillets by pricing for example, on the basis of relative color, presence of melanin spots and relative freshness.

The near certainty cultured caged Atlantic salmon will escape and potentially introgress with wild fish is now not contested by the industry. Negative impacts of accidental escape of farmed salmon and/or the direct introduction of hatchery stocks into wild runs has been documented many times in many places. Impacts on wild stocks result from genetic introgression, essentially the migration of genes from captive populations into wild populations via interbreeding. Natural mixing of genomes of captive fish that are adapted to specific artificial production environments with those of wild fish that are specifically adapted to local natural environments can result in local declines in wild population fitness because many traits selected directly or indirectly in captivity are not favoured in the wild (e.g. relative passivity/aggressiveness). The magnitude of this problem is proportional to;

1. The degree and importance of the adaptation of the wild population to the water body in question. In cases where only a narrow range of genotypes can survive in a particular water body, the genetic basis (variation) of the fish population narrows, rendering the wild population more vulnerable to impacts of environmental change,
2. The relative sizes of captive and wild populations. This can impact when wild fish populations are relatively small (i.e., <10,000 individuals) and are closely adapted to a particular ecosystems and are swamped by large numbers of stocked or escapee fish, such as is the case for many wild runs of Atlantic salmon. Consequences of reduction in wild
fitness can be catastrophic and even result in local extinctions of wild variation, even when total number of fish in the water body has increased.

3. The degree of genetic divergence between the gene copies in the wild fish and feral captive fish. The greater is the genetic divergence between the introduced and wild genomes, the greater in theory, would be potential negative impacts on population fitness.

4. The objectives of having both captive and wild fish in the same stream. If preservation of the native indigenous genetic variation is considered to be of higher importance, the increase in total fish numbers in a particular water body as a result of stocking or escapees may be less important than potentially negative impacts on relative fitness of the wild population.

In the case of small, highly adapted wild Atlantic salmon populations, introductions of large numbers of hatchery-reared fish has been shown in many cases to reduce overall wild population fitness. In contrast, long-term and large-scale releases of hatchery-reared marine fish fingerlings into wild populations (e.g. Atlantic cod, redfish and red sea bream) have generally failed to produce any noticeable change in wild fish populations, even in cases where effective breeding numbers have been significantly enhanced.

- **Implications for a potential East African genetic improvement program**

Aquaculture of Atlantic salmon is now a highly efficient way to grow and rear fish in open water cages in the ocean until they reach market size. Given below are details of factors that may have implications for development a genetic improvement program for EA. It should be noted that it is difficult to draw specific implications about factors that have worked in the salmon industry that could assist in EA Tilapia development or may be applied in an EA context because the status of research, technical and academic backgrounds are so different that have assisted the salmon industry development in Norway.

Three milestones are recognized in development of the Norwegian salmon-farming industry (NSFI). In 1969 net-pen production technology was established. In 1978, a Fish-Farmers Sales Organization (FSO) was established. In 1991 the FSO went bankrupt and this resulted in major amendments to Norwegian aquaculture legislation including removal of the ownership regulation. Over the years, NSFI has changed from a single farm locally-owned industry to a structure of a smaller number of very large corporations, while government policy has changed from direct support and engagement to more indirect engagement tasks including industry control and surveillance.

In 1969, a transition from trout to salmon farming and from fresh to seawater farming took place in the industry. The transition led to a net-pen farming system in seawater as the standard farming technology and to standardisation of siting specifications; ‘sheltered locations’, ‘seawater quality’, ‘proper current’ and ‘adequate depth’ became optimization criteria. Before this time, fish farms were located in a variety of different habitats, including freshwater and river systems and even on land. One major result of the change in siting specifications was increased demand for specific locations that were abundant along the inshore Norwegian coast.

Expansion to include trout in the breed improvement program brought a major change in market access. Trout are mainly produced for the Norwegian domestic market, while salmon production is largely focussed on high-value export markets. These changes accelerated standardisation of how and what to farm in local aquaculture. Farmers with the opportunity, converted to sea-based net-pen farming, and new recruits to the industry also adopted this approach where possible. Common technologies created a
more unified identification than had existed previously, making farmers’ experiences useful to each other. Salmon farmers in Norway in general, have refocussed on export markets as a result of increasing international demand for salmon and changes to technologies and expanding market access, increased communication and interaction among salmon farmers.

Transition to net-pen farming initiated standardisation of salmon farming technology, a change that was decisive for future organization of the industry. As a result of industry dependence on seawater sites, new fish farmers were now largely recruited from coastal communities. In the early 1980s the government followed a policy of equity with licenses distributed to as many applicants as possible in all parts of the country, provided they met minimum standard requirements. This policy initiated major tension in NSFI. Salmon was now an established, high priced international commodity, and how to organize NSFI as an export industry became the crucial problem to solve. The general problem was to maintain equity and viability of local farmers at a time when an increasingly international market favoured efficiency in sales and export.

In 1970s, farmed salmon trade was reorganized to include financing, this gave salmon farmers authority to finance their organisation via a fee. The Raw Fish Act provided fish farmers with centralized control over trade and thus a more predictable economy. In addition, this established a direct association with the fisheries and the fishing sector. This solution merged with salmon farmers interests and in 1978, they achieved an independent sales organization protected by the Raw Fish Act.

Currently, there are an estimated 37 aquatic stock improvement programs in Europe of which the majority apply family selection methodologies. While cumulative genetic gains in growth performance vary with program, efficient and well-designed stock improvement programs have had, and will continue to have, a major impact on development of European aquaculture and it is highly likely that in the future all farmed aquatic species across the region will rely on improved culture stocks.

3.3 Akosombo tilapia strain, Ghana

A. Objectives of the genetic improvement program

The objective of the Akosombo program was to develop an improved local strain of tilapia for the culture industry in Ghana. More recently, a second program was undertaken with the aim to investigate differences in body weight of males and females of seven tilapia strains at harvest and the goal of this program was to determine if crosses between specific genetic strains would show reduced sexual dimorphism for growth rate. This is because if sexual dimorphism could be reduced significantly then productivity could be increased without a requirement for developing male-only culture.

B. Location and geographic scope of the program

The program for Tilapia genetic improvement in Ghana that developed the Akosombo strain was initiated in 1994 by the Aquaculture Research and Development Centre (ARDEC-CSIR-Water Research Institute-WRI), Akosombo, Ghana. The approach adopted involved undertaking growth performance trials of wild local fish populations collected from three ecological zones and a farmed strain sourced from a local producer in Ghana that were compared in a 4 x 4 diallel cross. This led to development of the Akosombo strain and this strain subsequently became the nucleus of the breeding program for Ghana and the region.
50 to 100 fish families were developed from diallel cross stocks that have been performance tested annually with assistance from WorldFish. This breeding program is ongoing and continues to provide the best germplasm available to local farmers in Ghana.

In the second program, seven tilapia strains representing three different Tilapine species (Nile tilapia, *O. niloticus* (Abbassa strain, Akosombo strain, Malaysia GIFT strain); Blue tilapia, *O. aureus* (Abbassa strain, Israeli strain); Shire tilapia, *O. shiranus* (Bunda-Domasi strain) and a single hybrid (Red Tilapia, *Oreochromis* spp.) strain were assessed for relative growth differential of males and females within strain.

**C. Relevant wider aquaculture industry dynamics relating to the program**

Tilapias are farmed widely but at a variety of intensity in most African countries. In each producing country, captive populations have been established on farms and small-scale hatcheries developed. Combined effects of high levels of inbreeding, genetic drift, stock introgression from feral fish of poor quality, and inadvertent selection have often resulted in farm stocks showing poor productivity. Many farm stocks show growth performance currently as much as 40 percent below that of comparable local wild stocks. There have also been a number of studies that have indicated that levels of genetic variation within many cultured strains in Ghana is relatively low and this in general, may have impacted relative growth performance of farm stocks. These indications of ongoing poor stock management suggest that existing farm strains would be unlikely to respond positively in any new stock improvement program if they were used to establish a base population.

Recent years have seen a rapid growth of fish farming in a number of African countries as the private sector realizes fish farming can be profitable. Commercial farms (for profit) are now in production in, Angola, Cameroon, Congo, Ghana, Nigeria, Kenya, Madagascar, Malawi, Uganda and Zambia. Private sector responsiveness to this growing industry, combined with growing concerns about significant declines in fish supply from the wild, has promoted increased political awareness of, and support, for aquaculture development. Growing private sector investment is also helping to address chronic constraints on a lack of good quality seed and feed in some areas. Following removal or mitigation of these constraints, yields are increasing but new factors that limit output have become more apparent, in particular, the comparatively poor culture performance of many local culture strains. Frustration over poor performing local culture lines has been exacerbated by readily available information globally that has documented many times, the high performance of exotic tilapia culture strains like the GIFT fish and the “super” male strain outside of Africa.

Growing frustration from producers in several instances has led to unauthorized introductions of improved exotic strains of Tilapia back to Africa in contravention of the Nairobi Declaration on the ‘Conservation of Aquatic Biodiversity and Use of Genetically Improved and Alien Species for Aquaculture in Africa’. Producers however, are confronted with the possibility of achieving potentially significant production increases by farming ‘top-of-the-line’ culture stocks developed outside of Africa or if they conform to prevailing regional regulations and/or policies they are often forced to farm sub-standard, poor performing local strains. Profit potential will often tip the scales so that producers opt to import better performing strains illegally without government approval. A serious side effect of this practice can be impacts on wild, natural populations following introgression that result from escapes of improved, non-indigenous genotypes into local ecosystems.
Clandestine or even overtly illegal introductions of exotic improved culture strains are often facilitated by difficulties that regional Governments experience with ensuring adherence to existing rules and policies on exotic introductions. Borders can be porous and once a fish has been introduced into a watershed, populations are likely to expand naturally across drainages and probably more widely across the region of introduction.

Within the context of a rapidly evolving aquaculture sub-sector, a significant question is: “what can realistically be done about the use and movement of genetically improved fishes?” In addition to the obvious but rather unrealistic option of establishing ironclad controls on trans-boundary fish movements, more practical options include developing improved local culture strains that contain the same or similar sets of genotypes as local wild stocks and/or relaxing controls on fish translocations in specific circumstances to allow African producers access to improved stocks that are already available globally, under regulated conditions.

D. Overall business model and funding:

- **Overall structure and approach**
The first steps undertaken in the Akosombo breeding program at ARDEC were performance trials that compared performance of local wild and culture strains in different local production environments. These studies were conducted in 1999/2000 by local Ghanaian government fisheries staff. Following this, WorldFish joined the program to assist with the next phase to develop a high quality base population and to begin the family selection component. Procedures and techniques developed in the original GIFT program were applied to the Akosombo founding stock in a breed improvement program to develop a fast growth Akosombo strain via family selection.

- **Organizations involved**
Aquaculture Research and Development Centre (ARDEC-CSIR- Water Research Institute-WRI), Akosombo, Ghana,
WorldFish, European Union,
Japanese Government and World Bank

- **Value proposition**
Deterioration in productivity of local cultured tilapia stocks linked to declining genetic quality has been well documented in many regions of the world and can account for productivity losses of in the order of 40% or greater relative to wild stock growth rates. Poor hatchery management, especially where it results in high levels of inbreeding, strain introgression (with wild fish that enter the system) and impacts of the effects of indirect selection favouring poor culture traits are considered to be the major factors that produce declines in farm strain productivity. As fish farming expands in Africa, pressure on national and in some cases regional governments, is increasing to either develop improved indigenous culture stocks for local culture industries or to allow imports of alien cultured species and/or improved exotic strains. With the GIFT tilapia (an improved strain that can grow nearly twice as fast as most wild stocks) already in widespread production in Asia, African producers have limited opportunities in competitive markets unless they obtain access to improved seed.

To provide African farmers with realistic options for importing alien species for culture, FAO and WorldFish Center initiated a series of regional activities for public-private partnerships on fish genetic management and breeding aimed at:
1. Increasing hatchery management capacity in the private sector;
2. Increasing the capacity of government research and extension services to undertake genetic improvement programs on aquatic species, and;
3. Developing a local better-performing culture line of tilapia for grow-out

- **Funding and/or revenue model, and degree of commercial viability vs grant reliance**
  Almost 80% of funding for development of the improved Akosombo strain came from international donors that included; The European Union, Japanese government, WorldFish and World Bank, and national funding (mainly for salaries) Some income comes from selling fry and broodstock from the program that serves to cover costs of hapa nets, tags etc. In addition, fish that are disseminated to hatcheries and multipliers are sold at USD$3 for each broodstock individual that assists with operations of the program.

- **Operations**
  Operations for production and maintenance of the Akosombo strain are conducted by government organizations, i.e., various government departments responsible for Fisheries and Aquaculture as well as some NGOs and International Organizations. The main government organization was ARDEC-CSIR- Water Research Institute, and the activities associated with the second program (refer to objective section) were also carried out here.

- **Marketing**
  To date, some income has been obtained from sale of improved fry and broodstock from the stock improvement program in Ghana. This served to cover the costs of hapa nets, tags, etc. Improved fish are currently disseminated to hatcheries and private multiplier stations at 5 Ghana cedis (USD $3) per broodfish.

Fish resulting from the Akosombo program now contribute ~50% to market supply of farmed tilapia in Ghana while a Danish company, West African Fish Ltd. (WAF) contributes an additional ~30% (grown in cages in the Volta Basin). This company was established in 2007 as a joint venture between Palm Acres Ltd and Royal Danish Fish group A/S. It is located at Lake Volta in the eastern region, near Asikuma town. Their aim was to create a farm to produce high quality tilapia and be the most environmentally-friendly farm in Africa. O. niloticus is used, and the company produces its own broodstock and fingerlings for their own use, i.e., they are NOT sold to other farms. The hatchery is land–based while the grow-out facilities are located in Lake Volta where fish are grown in stages, first to 50g and then to 500g at harvest size. Fish are retailed and wholesaled and some sold directly to restaurants and hotels ([http://westafricanfish.com/?page_id=188](http://westafricanfish.com/?page_id=188)). In addition, several smaller private companies are producing farmed tilapia. Maleka Farms Ltd was established in 2009 and produces its own broodstock and fingerlings The strain of tilapia used however, is not reported. Tropo Farm Ltd buys improved broodstock from ARDEC and has also started limited scale breeding and multiplication station programs that use Akosombo strain genetic material as does Crystal Lake Ltd that produces fingerlings and fry also based on Akosombo material from ARDEC. It should be noted that in 2005, Tropo Farm Ltd contravened the ban on import of farmed tilapia and acquired GIFT from SE Asia. The company was penalised and required to destroy their GIFT stock as well all fish they held. The company recommenced production using the Akosombo strain

- **Relationship with hatcheries and grow-out farms**
  Currently, there are very few large tilapia culture farms or hatcheries in Ghana, and a significant challenge is providing expert training for new hatchery and grow out managers locally so that, for instance, material does not become ‘contaminated’ (i.e. introgressed with inferior local farm stocks) and/or increasingly inbred. In general, current producer ownership
structure is dominated by foreign companies with very few Ghanaian owned farms multiplier stations or hatcheries, due to the relatively high cost of land and capital costs associated with establishing cage culture in the country. Major hatcheries that use the Akosombo strain include; Tropo Farm Ltd and Cystal lake Ltd.

E. Technical strategy of the genetic improvement program – including:

- Technical approach to genetic improvement and key processes involved
  The first step in the Akosombo breeding program (at ARDEC) was to undertake performance trials, i.e., in 1999/2000 comparing performance of strains used to develop the base populations in different production environments. At this stage WorldFish came in to assist with a selective breeding program. The procedures and techniques developed by the GIFT program were applied in the Akosombo program.

Since the 2002 Nairobi Declaration on the use of genetically improved and alien species for aquaculture and the conservation of aquatic biodiversity in Africa, interest has expanded significantly in developing fish farming across the continent linked to new investment, increasing demand for fish protein from expanding human populations and declines in exploited wild fish stocks. In effect, the Nairobi Declaration reinforced strict controls on the importation of exotic species and stocks not indigenous to target regions. Little progress has been made however, in many areas on developing realistic indigenous alternatives to introduced exotic farm stocks. Following round-table discussions between regional government representatives, private sector fish farmers and international development agencies (FAO, WorldFish etc.), pressure grew to revisit the Nairobi Declaration, the Code of Conduct for Responsible Fisheries, Technical Guidelines for Responsible Fisheries, the Dhaka Declaration on Ecological Risk Assessment of Genetically Improved Fish and other related policy instruments that control or restrict exotic introductions in the face of the difficult realities of growing the fish farming sector across Africa. Output from this consultation was a set of guidelines for regional governments on how to address the growing demand for improved germplasm for aquaculture.

At the time (2002), participating institutions acknowledged a variety of issues that were acting either directly or indirectly restricting development of aquaculture across the continent. Issues identified included; that fish farmers outside of Africa enjoyed a large competitive advantage in domestic, regional and international markets due to their possession of, and easy access to broodstock from improved strains of native African fish species developed elsewhere, notably in Asia. The forum also recognized that maintaining the genetic integrity of high performing, selectively bred fish stocks thereby conserving their value in aquaculture, depends directly on maintaining the highest standards of hatchery management. They concluded that the physical and human resources necessary to replicate this development were not available at the time across much of Africa and so external assistance would likely be required to help develop the necessary infrastructure, to provide specialist training in expert fish breeding as well as applied genetics expertise to bridge the gap. In addition, it was acknowledged that expertise in best stock management practices and the development and use of cost effective feeds both of which are fundamental to any move from farming very basic, domesticated wild stocks to farming improved germplasm was also to a large extent not available as well. Following discussions on use of improved strains and informed brood stock management practices, the African commercial fish farming community proposed (to the international community, regional bodies and African national governments) to facilitate
rapid access to the best available strains of tilapia and African catfish for use on certified fish farms in Africa.

Responding to the valid concerns of natural resource managers about potential impacts of introduction of exotics on natural ecosystems, commercial fish farm operators committed themselves to a process that assured responsible business and farm management practices via submission to periodic inspection or other validation mechanisms to be implemented by lawfully delegated authorities. In addition, they undertook to adopt best management production and containment practices in accordance with the FAO Code of Conduct for Responsible Fisheries, the Convention on Biodiversity and other international covenants and conventions on protection of aquatic resources and the use of improved fish strains. They also undertook to support a system of reporting production by strain as well as scientific monitoring and evaluation to ensure that any unforeseen changes in stock abundance and diversity in wild indigenous tilapia and catfish populations would be quickly detected and that remedial actions could then be implemented rapidly. They also proposed to national and international bodies that they consider providing financial and technical support to establish an African Regional Fish Breeding Program to include and be based at new state-of-the-art breeding complex(es) that would cater for the need for high-quality genetic management in the short term, and continued long-term improvement of both native farmed African tilapias and catfishes over the longer term. An important part of this program would be establishing a seed and commercial aquaculture certification system that could serve to guarantee adoption of best management practices and that would also regulate distribution of fry and fingerlings produced for aquaculture. It was argued that this program was required urgently and should be implemented within 12 months. There are no specific details available as to what really happened, however we can assume that WorldFish supported the Akosombo programs with several donors providing financial resources.

- **Technology used in the development of the genetic improvement program**
  The original Akosombo strain was derived from a simple diallel cross of three wild populations of *O. niloticus* collected from the Volta system in Ghana and a farm strain from a local producer. In the second program, a total of 62,787 individuals collected from pedigree *O. niloticus* breeding programs (Abbassa strain, Akosombo strain, Malaysia GIFT strain); Blue tilapia, *O. aureus* (Abbassa strain and a selected line from Israeli); Shire tilapia, *O. shiranus* (Bunda College-Domasi selection line) and synthetic selection line of Red tilapia (*Oreochromis* spp. Jitra derived from stocks from Malaysia, Taiwan, and Thailand).

F. **Genetic improvement outcomes**

- **Estimated degree and nature of enhanced performance after the genetic improvement**
  The Akosombo strain became the nucleus of the national breeding program in Ghana, a program that is ongoing and that has provided a superior performing stock for regional farmers. The strain achieved growth rates ranging from 30% to 50% higher than those of other non-improved local farm strains in the region. A report by Kristen Rosenthal, Ingrid Olesen and Morten Walloe (2012) stated that access to, equity in, and protection of genetic resources in Ghana that domestic dissemination of genetically improved tilapia primarily went to farmers near or by Lake Volta where infrastructure and electricity supplies were good, and where local farmers can produce four times that of farmers who farm in rivers and ponds that are shallow and lack general infrastructure. The difference reported was 400-800g per individual produced in cages after 5 months, compared with a mean weight of about 250g after 6 months in ponds.
A secondary aim was to reduce sexual size dimorphism (SSD) previously a significant problem in local strains that resulted in some farmers considering the option of producing all-male populations because male *O. niloticus* can grow at faster rates than females. Results confirmed significant sex effect on growth rate in all strains tested and that magnitude of SSD varied substantially within and among tilapia species and strains in different production environments. This variation was considered likely to have important consequences on decisions to pursue mono-sex culture or not in the future.

Following from above, while there are indications that SSD for body weight is relatively stable within a given population or genetic group over an extended time period, it can also vary substantially among generations. There was little evidence from the work conducted to suggest that selection for fast growth rate could either reduce or increase SSD between the sexes after three generations of evaluation. The investigators concluded that further investigation on factors affecting SSD in tilapia would be required to better gauge the relative benefits of mono-sex male culture over mixed-sex culture, and whether it was even advantageous to culture mono-sex populations in some instances. Research investigating environmental factors that potentially contribute to changes in the magnitude of SSD in tilapia stocks may also provide indications as to changes to stock management practices that may help to reduce the disadvantages of large weight differences between males and females at harvest. The magnitude of SSD is often overlooked in tilapia farming yet SSD variation of the order identified here can have substantial impacts on relative stock productivity.

G. Lessons learned and implications

- **Critical success (or failure) factors: Strength and weaknesses**

  Many examples exist of the disastrous consequences of introducing exotic species into both aquatic and terrestrial habitats in Africa and elsewhere. While some have been accidental (e.g. common carp into Lake Naivasha, water hyacinth into Lake Victoria), some have been deliberate introductions (e.g. Nile Perch and Nile Tilapia into Lake Victoria). Many introductions have proven costly in both ecological and economic terms, and so any planned new fish introductions for farming should be based on solid evidence that it is unlikely that there will be negative consequences or compelling socio-economic and/or ecological evidence that could outweigh ecological concerns (e.g. the introduction of South American weevils into many African waterbodies to control a catastrophic weed like water hyacinth). Examples of the negative ecological and economic impacts of exotic fish introductions in Africa include;

  - Hybrid introgression leading to extinction of locally-adapted wild genotypes in places where *O. niloticus* will interbreed with related indigenous tilapine species (e.g. *O. andersonii* in the upper Zambezi).
  - Ecological displacement; competition for nesting sites between introduced *O. niloticus* and *Tilapia zilli* in Lake Victoria resulted in displacement of *O. esculentus* and *O. variabilis*.
  - Introductions of exotic fish diseases and parasites have caused significant damage to local indigenous fisheries and the human populations that rely on them.

A comparison of key biological and ecological traits of salmon & tilapias.

**Salmon**

- Top carnivore
- Relative few species
- Wild populations are often comparatively small with associated, highly locally-adapted and restricted gene pools
- Complex life histories and often highly adapted to ecological conditions in specific drainage systems
- Some taxa reproduce only once and then die

**Tilapias**
- Forage species, low trophic position on the food chain
- Large population sizes, even in smaller waterbodies
- Most wild stocks have high levels of genetic diversity,
- High levels of phenotypic plasticity; not specifically adapted to local habitats
- Reproduce multiple times per year

**The risk of importing ‘exotic’ farmed tilapia strains for fish farming in Africa**

While currently, there have not been any documented cases of negative environmental impacts elsewhere in the world or in Africa, *O. niloticus* is a ‘weedy’ species that can survive in suboptimal environments and in theory, could disrupt aquatic ecosystems were it to be introduced into pristine habitats. Introductions of non-indigenous strains of *O. niloticus* to places where it currently does not occur should therefore be carefully considered. As most captive populations will eventually find their way into the wild, a cautious approach when considering transfer and farming of non-indigenous *O. niloticus* strains in non-native watersheds should be considered when it is not feasible to develop local strains for farming.

The principle concern of wildlife conservation biologists in regard to importing domesticated tilapia strains back to Africa for farming is related to their potential to introgress with wild indigenous populations that likely contain unique genetic variation (often not exploited to date) that is of adaptive significance and if developed carefully, could be of economic importance in captivity. Differences in potential to cause genetic erosion do exist however, between Atlantic salmon and tilapine species.

While it must be stressed that there is no compelling empirical evidence arguing either for or against the possibility of negative impacts resulting from the introgression of captive tilapia strains into indigenous populations, the substantial differences between tilapia and salmon (upon which most of the concerns over genetic erosion are based) imply that the risks of introducing improved tilapias specifically for aquaculture could be significantly less than for Atlantic salmon.

Referring to the list of conditionality’s presented above:
1. Tilapia are generalists and not normally closely adapted to specific ecosystems.
2. Wild tilapia populations are generally extremely large, in excess of millions of individuals, while escapes from aquaculture are minimized by farmers trying to protect their investment.
3. In terms of growth performance, in general well managed, domesticated populations of tilapia grow 40 to 60% faster than wild populations.
4. Food security and economic growth in impoverished communities are key concerns.

Only point 3 (above) gives substantial cause for concern. If, for example, there are serious threats to an indigenous local tilapia population of particular significance to local capture fisheries or of special value as a locally adapted race, large differences between captive and wild fishes could represent a real danger. Dangers associated however, with genetic differences are proportional to the absolute value of the difference, not whether the difference is positive or negative.

At present, hatchery populations across Africa are substantially different from wild populations, mostly in a negative way. From developments so far, it can be seen that the difference between the threat of introducing an improved farm strain (GIFT as an example), is not measurable in terms
of risk, but in time; ten years in this case. That is, if an African hatchery either begins breeding its own indigenous improved line, or if the current negative situation continues, whatever the absolute danger to wild populations may be, it will be eventually realized regardless of whether the GIFT is introduced or not. It just requires sufficient time. This means essentially while the risk is very similar, exotic strains likely carry copies of genes that do not occur in local stocks, so potentially they pose a more serious problem if they introgress widely in the wild.

There are two additional realities that should not be ignored when making decisions about conservation of indigenous tilapia biodiversity in Africa:

1. O. niloticus has been introduced widely into thousands of waterbodies across the continent from at least the 1940’s. Many of these introductions have resulted in feral populations establishing.
2. Commercial fish farmers, who are facing increasing competition in both local and international markets from foreign producers using improved strains of tilapia, have in the past made illegal introductions and, faced with potential for their businesses to fail, may well resort to such tactics in the future.

Regardless of whether a decision was made to import an exotic improved breed of O. niloticus for culture in EA rather than develop one locally, Msinji should be encouraged to work with local hatcheries to breed their own local strains as risks to the environment and the livelihoods of local people are essentially unavoidable. A careful cost/benefit analysis and risk assessment, following recommendations from the Nairobi Declaration on the Conservation of Aquatic Biodiversity and Use of Genetically Improved and Alien Species for Aquaculture in Africa had been proposed within the prevailing ecological and socio-economic contexts. Undertaking the risk assessment however, was not easy considering an overall lack of availability of hard scientific data. At least in the case of O. niloticus however, the threat of major ecological damage resulting from the importation of improved strains for aquaculture in watersheds where it is either indigenous or feral would appear to be relatively low.

To ensure that any problems that do arise following an exotic introduction are quickly identified and measures put in place rapidly to address them, any importation should be approved only in conjunction with a monitoring and evaluation program. Main elements of such a program should include tracking and measuring rates of genetic introgression and monitoring of fish catch trends.

- Implications for a potential East African genetic improvement program

In general, there is little to learn for an EA program from the Akosombo program, and if anything is applicable, it is probably what not to do rather than what to do. Some relevant information in relation to establishing a genetic improvement program for EA is provided in Appendix 2.

3.4 Progift Aquaculture, China

A. Objectives of the genetic improvement program

Three Genetic improvement programs on tilapia were conducted by Progift:

Program 1: To investigate genetic parameters and selection responses for growth of Nile tilapia (O. niloticus) after six generations of multi-trait selection
**Program 2:** To investigate genetic parameters and selection responses for growth, pond survival and cold-water tolerance of blue tilapia (*O. aureus*)

**Program 3:** To investigate genetic parameters and selection responses for growth, survival and external colour traits on Red tilapia (*Oreochromis* spp)

**B. Location and geographic scope of the program**

Programs were conducted by Hainan Progift Aqua-Tech Co., Ltd, a private company in China with technical supervision provided from Akvaforsk (Norway).

**C. Relevant wider aquaculture industry dynamics relating to the program**

Tilapia is an important culture species in China with annual production of more than 1.3 million mt. Guangdong, Hainan and Guangxi rank as the top three Provinces for annual production of tilapia in China. Even after two decades of rapid growth of tilapia production, over recent years China is still facing many challenges with developing the industry.

While national tilapia hatcheries in China in general, produce good-quality seed, some smaller hatcheries have experienced quality issues.

To better understand the sustainability constraints facing China’s aquaculture sector, a study conducted in 2010-2011 by the Sustaining Ethical Aquaculture Trade project, the Science and Technology Commission of Shanghai Municipality and the National Natural Science Foundation of China indicated that sustainable development of the tilapia industry depended largely on factors that included; market price, disease control, water quality, climate, seed supply and seed quality.

Specifically, the study found that:

1. Market price of tilapia had changed significantly in recent years with price of 500gm live fish dropping to only U.S$0.16/kg (7 yuan/kg). In response, many tilapia farmers have changed to stocking carps or other freshwater species. Total culture area in Guangdong, Hainan, Guangxi and Fujian Provinces declined as a consequence.
2. In 2011, market prices reached 10 yuan/kg but this price was still marginal for almost 50% of farmers raising tilapia as a stand-alone enterprise. Integrated farms were in general, more resilient, with profits from pigs compensating to some extent for any losses from farming tilapia.
3. Incidence and severity of disease has increased in recent years with *Streptococcus* infections and hepatobiliary syndrome becoming major diseases linked to average summer temperatures above 35 degrees Celsius that have impacted tilapia production.
4. A typhoon ravaged the western coastal areas of Guangdong in mid-2010 that directly damaged many tilapia farms and caused significant broodstock and grow out fish escapes from ponds. In the same year, Typhoon Megi ravaged Hainan and devastated 80% of farms there. Both cyclones also increased disease problems with surviving stock on some farms.
5. Quality problems were observed in Hainan that suffered unusually high mortality and similar problems were observed in Guangdong. Poor seed availability persisted across the year in Guangdong, Hainan and Fujian, and the price of juveniles remained higher than normal.
6. Costs of labour, feed, chemical and infrastructure have greatly increased over recent years. Labour rates have increased by at least 50% across the same timeframe.
As a result of the issues identified above Akvaforsk Genetics Center (AFGC) was engaged by Hainan Progift Aqua-Tech Co. Ltd (Progift Aquaculture) to design tilapia genetic improvement programs for the local industry in China:

- Program 1 at a tilapia hatchery in Taishan County, Guangdong Province.
- Program 2: at Dingan County, Hainan Province.
- Program3: at Dingan County, Hainan Province (3 locations)

D. Overall business model and funding – including, where possible:

- Overall structure and approach and organizations involved
  ProGift genetic improvement programs are operated and managed by Hainan Progift Aqua-Tech Co. Ltd. Some unofficial reports have suggested that funding was sourced from a commercial loan to finance operations. Unfortunately, even after intensive surveys, there is very little direct information available about funding OF the projects. Organizations involved include:

  - Hainan Progift Aqua-Tech Co. Ltd
  - AFGC

- Value proposition
  Quantity and quality of tilapia seed in China had become a significant bottleneck limiting expansion of tilapia culture in China. Following rapid development of tilapia farming in 2003, existing hatcheries were not able to meet the huge and growing demand for tilapia seed. Recognising that tilapia seed production was dominated by a relatively small number of large hatcheries, and the need for tilapia seed production to be decentralized, smaller hatcheries were established by Hainan Progift Aqua-Tech Co, Ltd in partnership with Akvaforsk Genetics Centre (Norway). The main purpose was to develop genetically superior breeds of tilapia to meet future demand for tilapia in China and as well as globally. Existing tilapia strains in China were a major constraint on tilapia production because they showed slow growth rates, poor reproductive output and production performance, poor disease resistance and a low % of male Nile-Blue hybrid tilapia were available at the time. In addition, most producers did not have money to invest, land was in short supply and water and energy costs were rising. Production areas had also been damaged by climatic events. All of these factors contributed to interest by the company (Hainan Progift) to develop and pursue a tilapia stock improvement program.

At the time, several state-owned tilapia stock farms had been established in Guangdong, Shandong, Jiangsu and Hainan Provinces to maintain tilapia strains and to conduct genetic breeding programs. Tilapia is mostly cultured by small-scale farmers who have only limited technical knowledge and so level of stock management was generally poor, resulting in poor quality product. A business model practiced by some large processing companies operating at the time, involved “company + base farm + farmers”, where companies provided good quality seed, feed and technical services to farmers and then, purchased back adult tilapia for the market. This model was a good way to link small-scale farmers to larger markets, and hence to enhance healthy development of tilapia culture. Progift reasoned that this model would benefit from availability of a genetically improved breed of tilapia linked with an efficient system of seed multiplication and dissemination and so Progift Aquaculture took the opportunity with advice from Akvaforsk to build the largest tilapia hatchery in the world with an annual capacity to produce several billion genetically improved tilapia seed.

- Funding and/or revenue model, and degree of commercial viability vs grant reliance
  All programs were privately funded and did not rely on grants from either government or external donor sources. It has become one of the most highly successful commercial tilapia genetic improvement programs in the world, and continues to excel.
• **Operations**
The three genetic improvement programs were supervised by AFGC and managed by Hainan Progift Aqua-Tech Co. Ltd. While different procedures and methods were followed to produce the three genetically improved tilapia stocks in the Progift program, reports indicate that in general, most hatcheries were stocked at 1 fish/m² with female Nile tilapia crossed to male blue tilapia at a ratio of 3:1 in earthen ponds of 1,200-2,500 m² in surface area and 100-120 cm in water depth. Broodstock are fed an artificial feed (32-38% crude protein) twice daily (1100 and 1700 h) at 0.5-1.0% bodyweight per day. A few days later, Nile-Blue hybrid tilapia fry are harvested using fine mesh seine nets. Harvested fry are then distributed to other parts of China, nursed in local nursery farms until they have reached 2-3 cm long, and are then sold-on to grow out farmers at an average price of 0.1 Yuan/fry (1US$=8.21 Yuan). Male% of Nile-Blue hybrid tilapia fry ranged from 85% to 90%. Male hormone (17-methyltestosterone, MT) was added to feed (38-40% crude protein; 50 mg MT/kg feed) to treat Nile-Blue hybrid tilapia fry to increase male % to reach 98 to 100%. Hybrid fry were harvested and stocked at 4,000/m² in outdoor cement tanks of 20-50 m² in surface area and 100-120 cm in water depth. Concentration of dissolved oxygen in the tanks was maintained above 2.5 mg/L through 24-hr aeration. Nile-Blue hybrid tilapia fry were fed MT-feed 4 times daily (0700, 1200, 1800 and 2200 h) at 10-15% body weight per day for 15-18 days. When they had reached 2.5 cm long, fry were transferred to hapas suspended in earthen ponds and fry nursed for 4-5 days before sale. Fry survival ranged normally from 90% to 95%.

• **Marketing**
Tilapia are cultured in China mainly in semi-intensive systems on small and medium to large commercial farms. While in general tilapia farming is very profitable, stock productivity and cost of production and profitability varies considerably among provinces and in different production environments. In recent times, tilapia farming has become increasingly commercial. Little information is available on how the company markets its improved lines or the cost involved as it is a private entity and the information is restricted.

• **Relationship with hatcheries and grow-out farms**
Hainan Progift Aqua-Tech Co. Ltd has developed an effective dissemination system for genetically improved tilapia seed. It owns the world’s largest tilapia hatchery and several satellite stations in the major tilapia producing areas in China. Hatcheries employ hapa breeding and artificial incubation of fertilized eggs and have a capacity to produce >1 billion tilapia seed per year. The company also distributes Blue tilapia and a Red tilapia strain to all common production systems in China.

E. **Technical strategy of the genetic improvement program – including:**

• **Technical approach to genetic improvement and key processes involved.**
Tilapia culture has expanded rapidly in China since the early 1990s. Blue tilapia (*O. aureus*) was first introduced to China in 1981 from Taiwan by Guangzhou Fishery Research Institute and in 1983 from USA by Freshwater Fishery Research Center of the Chinese Academy of Fisheries Science, respectively. Nile-Blue hybrid tilapia, a cross between female Nile tilapia and male Blue tilapia, was produced successfully in 1984 and since this time hybrid tilapia have emerged as the most important tilapia strain in China. Attributes that have made hybrid tilapia popular include a high male ratio (85-90%), relatively fast growth, large size, good cold-tolerance, and wide tolerance range of different environmental salinities. The advantage of high male percentage has to a large extent, addressed the problem of early sexual maturation and unwanted reproduction common in many pure strains of
tilapia. Farming hybrid tilapia has increased both production levels and economic returns from tilapia farming, making tilapia now one of the major cultured fish species in China.

The GIFT strain was first introduced to China in 1994. The 9th GIFT generation (2,000 broodstock) - GIFT-strain Super Tilapia, or GenoMar Supreme Tilapia™-GST) was introduced later in December 2001 and evaluated against the local commercial strain in China. Results showed that the GIFT strain Super Tilapia grew more than twice as fast as the local commercial strain. GenoMar ASA then established a large hatchery (GenoMar Supreme Hatchery China, GSHC) to produce the super tilapia strain in Hainan Province in cooperation with a private Chinese company for large-scale dissemination of the GIFT-strain. Sale of fry from this strain started in June 2002. Since then, millions of fry have been harvested and sold to private farms mainly in Guangdong but also in Hainan. In 2004, a new generation of improved GenoMar Supreme Tilapia™ that showed a 20% increase in growth rate and a 10% reduction in FCR were introduced to China by GSHC. Red tilapia (O. spp.) has also become increasingly popular since 1990, due mainly to success with selection of better strains and increased preference for red fish by Chinese consumers. In 2000, Charoen Pokphand Foods Public Co. Ltd. (CP Foods) from Thailand introduced 100,000 Thai Red tilapia from Thailand to Hainan Province for distribution and seed production on its own private farm.

Following from above, AFGA has worked with Progift aquaculture since 2004, developing three superior breeds of tilapia- Progift Nile (O. niloticus), Progift Blue (O. aureus) and Progift Red (O. spp). Initial years of development focused on adapting selective breeding technology to local conditions and building local competence in managing tilapia breeding programs.

- **Technology used in the development of the genetic improvement program**
  AFGC supervised the three programs (Nile tilapia, Blue tilapia and Red tilapia) run by Progift. The three programs were established using breeding technology developed for Nile tilapia in the GIFT project in the Philippines (i.e. the GIFT technology, WorldFish Center) but with modifications made to assure sustainable development of these programs.

  **F. Genetic improvement outcomes**

- **Estimated degree and nature of enhanced performance after genetic improvement**
  Program 1: To investigate genetic parameters and selection responses in growth of Nile tilapia (O. niloticus) after six generations of multi-trait selection.

  - Mean harvest weight increased from 340 to 800g across the seven generations tested. Increase in harvest average weight was the result of both genetic improvement of growth performance (after a total of 16 generations of selection) that increased average weight from 50 to 160g and 170 to 230g in the seven generations tested in Vietnam. Modifications included using a slightly older age at harvest and testing fish in more intensified production systems.

  - Males and females were tested in separate earthen ponds after expected time of sexual maturation to avoid negative effects of reproductive behavior on growth. Estimated genetic correlations between bodyweight recorded at expected time of sexual maturation and at harvest decreased with increasing number of selection cycles in both ponds and cages, indicating that time when growth is recorded (i.e., before or after sexual maturation) is as important as G x E effects.

  - Selection responses were estimated after six generations of selection based on comparisons with performances of control groups. Estimated average selection responses of 11.4% (range 7.4 to 18.7%) and 8.0% (range 5.0 to 13.2%), respectively, were comparable with many cited in the literature.
Accumulated inbreeding after six generations of selection was 5.0%, and this was lower than has been recorded elsewhere. Overall, realized selection response suggested an accumulated genetic improvement of 60 to 90% increase in bodyweight at harvest compared with the base population imported from Vietnam.

Program 2: To investigate genetic parameters and selection responses in growth, pond survival and cold-water tolerance of blue tilapia (*O. aureus*)

- GIFT technology was successfully adapted to establish a multi-trait selective breeding program, resulting in genetic improvement of growth (about 70% larger bodyweight at harvest) and better pond survival after four generations of selection.
- Inclusion of cold-water tolerance in the selection index counteracted a possible negative correlated response.

Program 3: To investigate genetic parameter and selection responses in growth, survival and external colour traits on red tilapia (*Oreochromis* spp)

- The program resulted in considerable genetic improvements in growth rate, survival rate and external colour traits after four generations of multi-trait selection.
- The program recommended that generations of families be tested in both freshwater and brackish water pond environments.

G. Lessons learned and implications

- **Critical success (or failure) factors/ Strengths and weaknesses of genetic program structure**
  The genetic improvement programs are operated and managed by a private company and supervised by a world-renowned organization (AGFA) and have been very successful. No records of failure have been reported, except from natural disasters (cyclones and typhoons).

- **Implications for a potential EA genetic improvement program**
  It should be noted that ProGift is a totally commercial operation and the companies focus is solely directed towards profit, thus the operations due not account for needs of poor farmers or even middle level operators re engaging them in a new industry. There may be opportunity to replicate ProGift in EA when there is opportunity to develop a large commercial, profit-based, high value industry in the future.

For Progift Nile tilapia, selection responses for growth after six generations of multi-trait selection were on average, 11.4% per generation. In addition to growth, survival rate has also been major trait of interest. In the GST strain growth rate increased by 35% after 17 generations of selection. Currently, GST produces a new generation every nine months with a genetic gain in growth rate of more than 10% per generation (GenoMar Breeding Services, 2016). Since development of the GET-EXCEL strain in 2002, it has been claimed to achieve 38% better growth rate and yield compared with unimproved tilapia stocks. The GIFT program has been best documented, with average genetic gains for harvest weight of 10 % per generation over 10 generations of selection. In addition to harvest weight, other traits including; body dimension, fillet yield and body shape traits have been studied across GIFT.
generations. To date, improved Nile tilapia strains from the GIFT breeding program have been widely distributed from Asia to many parts of the world.

In EA and more generally in sub-Saharan Africa, smallholder farmers grow Nile tilapia either using fertilization with organic material alone or with a wide variety of locally available farm resources, making farming conditions quite diverse. It can therefore be hypothesized that breeding objectives for farmers are likely to differ depending on the diverse farming conditions adopted. This is an issue that has not been addressed until now. In addition, economic assessment of cost and revenues for Nile tilapia based on farming conditions are rare. Estimation of economic values for breeding objective traits to evaluate their economic relevance are therefore, still lacking. Developing relevant breeding objectives that will maximize economic returns will be a prerequisite for sustainable genetic improvement programs for smallholder production of Nile tilapia across the region.

In Africa, selective breeding programs for Nile tilapia are based on the development of new improved lines from local strains targeted at improving final harvest weight. This includes the Abbassa and Akosombo strains of Nile tilapia. These local strains have to exhibit high genetic variation for the traits of interest. Estimated genetic parameters for breeding goals for specific traits to quantify this variation for Nile tilapia are still lacking. In addition, selection is practiced at breeding stations generally in relatively good, controlled environments, yet realised responses in farm environments are often still very poor. There are also reports that genetic gains from selection in breeding programs carried out in good environments were often lost or reduced when improved breeds were tested in less favourable farm environments. This suggests that growth in different culture conditions is subject to G x E interactions. To avoid such interactions, selection process should carefully incorporate evaluation in low in-put production systems, where farmers grow Nile tilapia using fertilization with organic material alone or with a wide variety of locally available farm resources. A variety of reports have shown that better performance of Nile tilapia in Africa can be achieved through genetic improvement when local strains are improved. Existing improved strains like GIFT tilapia, should not be used however, to introgress with fast growth local strains in most African countries, as GIFT is currently considered an exotic crossbred species, and would pose a risk to the genetic integrity of wild tilapia. This therefore necessitates development of local breeding programs to develop improved indigenous farm strains.
4.0 Focus and Approach of the organization, including

i. Strong areas of expertise and relative weaker areas

1. WorldFish Centre: GIFT Program
   (a) Positive features:
   - Focus very much on assisting developing countries to develop fish farming rather than direct commercial returns
   - Strong links with international bodies
   - Excellent relationships with government fisheries/aquaculture agencies
   - Access to scientists, research facilities, resources and partners in many countries
   - Extensive experience with stock improvement in many parts of the world.
   - Strong focus on G x E effects
   - Had some of the best practical stock improvement staff available following original initial developments
   - Adopt very active hands on engagement projects
   - Actively continue programs beyond initial developments
   - Addresses dissemination of fry, satellite hatcheries, marketing etc. issues as part of the broader focus of a program
   - Successfully moved from product development to new industry model
   
   (b) Negative Features:
   - Many of original staff have left WorldFish and replacements have different areas of expertise
   - Expertise in aquatic stock improvement was largely developed in first GIFT program with supervision from Akvaforsk
   - Recently, more interest in financial returns to WorldFish from partnering projects than in actually running projects directly

2. Akvaforsk: salmon genetic improvement program
   (a) Positive features
   - World best expertise in animal breeding, quantitative genetics and stock improvement
   - Large and highly qualified team
   - Extensive experience of working in developing countries in Asia, Africa and South America
   - Very experienced at working in Public-Private Partnerships (PPPs)
   - Builds expertise in partners via academic and technical training
   - Focus is on practical outcomes of programs
   - Strong focus on engaging with industry to deliver outcomes
- Can take on oversee management role in improvement program
- Have developed many tools and methodologies used by other groups

(b) Negative features
- Now a private company so goals are more focused on commercial return rather than research and development partnerships
- Relative costs of engagement have increased
- Direct academic/government research linkages have reduced over time with privatization
- Reduction in focus on skill exchange/capacity building in partners
- Early projects were very well funded on high-value, cold water species produced in optimal production environments using best technologies available, so best options, resources and conditions assisted positive outcomes. Can be more difficult and less effective in low resource rich conditions
- Approach can tend to favour larger, integrated producers and production systems over time at the expense of small producers

3. ARDEC-CSIR Akosombo program: Akosombo tilapia strain
   (a) Positive features
   - Achieved reasonable success with limited resources
   - Demonstrated that stock improvement could be achieved successfully in West Africa
   (b) Negative features
   - Relied very heavily on external partnership input to drive program
   - Limited evidence for development of local capacity in stock improvement
   - Overall impact of project has been limited in scale and has degraded due to limited local expertise
   - Impact on local farming industry is limited in scale
   - Did not really even try to address feed, fry dissemination, hatchery diversification issues to any significant degree
   - Potentially could impact native gene pools if farmed fish (new Akosombo strain) mix with native tilapia and interbreed

4. Progift Aquaculture, China: Progift tilapia breeds
   (a) Positive features
   - Took the improved GIFT fish to a new level increasing scientific knowledge and technology into development of new improved tilapia strains
   - Tackled improvement of new traits of particular relevance to culture in specific region (e.g. cold tolerance)
• Successfully leveraged off previous programs without impacting local gene pools
• Not dependent on accessing external funds or funding agencies

(b) **Negative features**
• Total focus on commercial return
• No impact on capacity building more broadly in China
• Akvaforsk provided technical program capacity
• Smaller local producers and communities may be impacted by competition from Progift

ii. Whether the organization is focused on academic research, training/capacity building and/or has high quality direct operational experience of genetics improvement programs

1. **WorldFish**: GIFT program
   • Focus was on assisting developing better culture industries in developing countries
   • Addressing poverty, livelihood enhancement and capacity building
   • Possessed very good, high quality direct operational experience of genetic improvement programs but modern staff replacements are in different areas
   • Focus is now more on facilitation rather than direct project management and active running of improvement projects

2. **Akvaforsk**: salmon genetic improvement program
   • Best available human expertise in aquatic stock improvement worldwide
   • World leaders in technology development and improving analytical capacity and tools in Quantitative Genetics and aquatic stock improvement
   • Relative level of focus on academic research has declined with privatization but still actively engaged in publishing new developments and postgraduate training
   • Relative focus on capacity building in partners has taken a more commercial focus (provision of training)

3. **ARDEC-CSIR Akosombo**: Akosombo tilapia strain: Akosombo tilapia strain
   • Relied on external partners almost exclusively for specific QG expertise and project direction
   • Some training/capacity building provided but limited in scale
   • Project staff had limited direct experience or expertise in stock improvement projects elsewhere

4. **Progift Aquaculture**: Progift tilapia breeds
   • No academic training or capacity building offered to external clients
   • Focus is totally on commercial development
   • Relied totally on Akvaforsk for stock improvement expertise
5.0 Strength and weakness of each organization

1. **WorldFish**: GIFT program
   - Broad experience of stock improvement programs in developing countries
   - Extensive collaboration with government and academic networks and institutions
   - Direct expertise in QG and aquatic stock improvement has been reduced from previous levels
   - Now focused more on capacity building and facilitation of programs

2. **Akvafors**: salmon genetic improvement program
   - Premier institution in the field
   - World’s best expertise, technology and capacity
   - Leading both practical and academic development in the field
   - Commercialization focus has increased costs of engagement and reduced external academic training focus

3. **ARDEC-CSIR Akosombo**: Akosombo tilapia strain
   - Largely reliant on external partner advice for project direction and management
   - Focus is on local development in Ghana, not really in a position to contribute significantly elsewhere
   - Outputs have been limited in scale and long term benefit within country

4. **Progift Aquaculture**, China: Progift tilapia breeds
   - Totally internally focused on commercial outcomes
   - No broader interest in wider capacity building or expertise exchange
   - Essentially adapted existing program (GIFT) to local production conditions with external paid partner support
6.0 Appraisal of the most relevant organization for the East African context

We consider that it is clear from the detailed information and comment provided on the four stock improvement programs provided above agreed for review in Phase 1 that the most appropriate organisation to assist stock improvement in EA is the modern persona of Akvaforsk i.e. NOFIMA Marin. The only alternative potential contender of the four programs reviewed, in our view would be WorldFish Centre. Given however, there has been significant turnover in staff at WorldFish with the necessary expertise and experience over the last 5 to 10 years and that much of the relevant practical expertise developed in stock improvement in GIFT programs and related projects in the 1990s and 2000s are now no longer with the organisation and expertise of their replacements are in different areas of aquatic science (e.g. Population Genetics and Biodiversity assessment), we believe that the organisation has less to offer than it did in the past. The exception would be if a decision were made to use improved exotic germplasm (GIFT) to initiate the new stock improvement program in EA. Under this second scenario it would then be very logical to consider engaging WorldFish as they have control of the modern GIFT germplasm and have assisted many institutions to develop farming based on this improved line.

There is little doubt in our view that, providing appropriate resources can be identified and applied, that engaging with Nofima Marin in a program of stock improvement for indigenous EA strains of Nile tilapia (potentially involving both existing farmed and wild strains) can address Msingi’s project objectives successfully and more specifically, contribute significantly to Msingi’s regional development goals identified in the original project profile.

Issues that we believe require some consideration by Msingi in this regard if Nofima Marin were chosen as the Expert partner in a stock improvement program for indigenous Nile tilapia in EA, that have been made potentially more challenging in our view since complete privatisation of Akvaforsk (focus is now directly on commercial return from external project involvement rather than inclusion of broader aims as in the past) include;

1. The relative cost of engaging Nofima Marin is likely to be higher than an equivalent program engagement with WorldFish Centre because WF can potentially leverage international development opportunities.

2. Capacity building of regional staff and local facility development will be critical to long term and ongoing sustainability of the program, so identifying ways to achieve this with Nofima Marin and regional academic and relevant governmental institutions from the start will be very important. Identifying and supporting local regional scientists and animal breeders to develop their academic and technical expertise in the various aspects of aquatic stock improvement, feed optimisation, industry development etc. in capacity building programs built into the main project can address this issue. If this cannot be achieved directly through Nofima Marin then engaging additional partners (e.g. Stirling, Auburn and/or Wagenerin university) to provide capacity building in specialist areas we believe to be another option. This will be crucial to long-term sustainability of the program. We note that a number of otherwise successful stock improvement programs in the Asia and the Pacific region and elsewhere have been less successful over the longer term simply because local capacity building to maintain and extend the programs was not addressed at the time. Potentially (e.g. in the original GIFT program), this issue at least in part, was addressed by engagement with local academic (e.g. U. Philippines) and international (U. of Wales) institutions.
3. Broadening the direct impacts of the program more widely to EA partners is also a potential issue, given that all or even most of the developmental phases of the project we believe cannot be conducted in all partner countries. Obviously regional partnerships and development can occur in various ways, but having a clear strategy for how this should develop evenly or at least strategically in our view, will be important to consider from project commencement.

A way forward
Arguments presented earlier have discussed the various pros and cons for use of either exotic or indigenous strains in stock improvement programs but in general, a conservative approach to conserving wild diversity is for government and private aquaculture sectors in EA to favour developing indigenous improved lines locally, where it is possible and the necessary resources both physical, technical and human are available.

External support can be channeled through Msingi over the immediate term using this issue as the topic for technical seminars in addition to considering establishing *ad hoc* Working Groups. At the same time, more substantial support for the East Africa Regional Fish Breeding Program needs to be procured and the program implemented.

A nucleus breeding system will require certification both of technical quality and management practices developed for broodstock production and with regard to quality of the brood stock animals sold to the industry. A similar type of certification procedure needs to be developed for core hatcheries as well as satellite hatcheries and nurseries producing an improved local line. We believe that growers should be both licensed and authorized to produce improved strains; authorization should be based on a composite of factors including; overall level of management skills, containment, and general technical capacity.

Based on reports from past workshops and farmers, principal focus groups have stressed the urgent need to take tangible steps toward addressing the complex issue of using externally improved strains. Producers made strong statement about their readiness to establish real and functional public/private partnerships. Nonetheless, some segments of the private sector want fast action and this has resulted in some exotic improved germplasm already having been imported illegally into a number of African countries and then even moved among watersheds. Uncontrolled and unregulated introduction of such strains will only be controlled when the private sector is confident they have access to improved local strains via official channels.
Appendix 1 International Network on Genetics in Aquaculture (INGA) and the Genetic Improvement of Farmed Tilapia Foundation International, Incorporated (GFII)

Success with breeding efforts to develop GIFT (1988–1992, Phase 1) required complementary structures to enhance and sustain GIFT-related activities. At the time, it was recognised that variation among farmed fish stocks, different farming systems and production environments made it imperative to improve aquaculture species via regional and international cooperation. Hence, at the suggestion of UNDP, ICLARM and 13 developing country members formed INGA in 1993. Ongoing development of GIFT (1993–1997, Phase 2) led to the establishment of GFII with a role to disseminate GIFT to INGA partner countries.

International Network on Genetics in Aquaculture (INGA)

UNDP recognized that GIFT and GIFT-related technology had created the first time in the history of tropical aquaculture, a situation similar to that for international evaluation of improved terrestrial crop varieties. In 1993 UNDP provided USD $65,000 to establish INGA, a group patterned on the UNDP-funded International Network for Genetic Evaluation of Rice that had been very effective developing networking for rice genetic improvement. INGA was initiated in July 1993 with membership from 11 developing member countries (Bangladesh, the People’s Republic of China [PRC], Côte d’Ivoire, Egypt, Ghana, India, Indonesia, Malawi, Philippines, Thailand, and Vietnam) and with ICLARM as the member-coordinator. Fiji and Malaysia joined INGA later in 1996. Based in Penang, Malaysia, at the headquarters of WorldFish Center, INGA invited 12 advanced scientific institutional members from across the globe to be associate members; Agricultural Research Organization, Israel; Auburn University, United States; Fish Culture Research Institute, Hungary; Food and Agriculture Organization of the United Nations; AKVAFORSK; National Research Institute of Aquaculture, Japan; Queensland University of Technology, Australia; Aquaculture Department, Southeast Asian Fisheries Development Center, Philippines; University of Stirling, United Kingdom; University of Wales, Swansea, United Kingdom; Wageningen Agricultural University, Netherlands; and WorldFish Center, Malaysia that had expertise in fish genetics and aquatic stock improvement. Three new organizations were added as associate members later, Asian Institute of Technology, Thailand; GFII; and University of Western Australia, Australia.

As an international network, INGA’s mandate included; to strengthen national research capacity for applying genetics in aquaculture, fostering regional and international cooperation, and assisting development of national fish breeding programs, with a focus on tilapia and carps. INGA also supported conservation of wild biodiversity of target species notably tilapia and carps, and other native fish species.

Since 1993, INGA has developed international partnerships and links for dissemination, information exchange, and further development of the GIFT strain. INGA member countries identified projects linked to national priorities, many of which were common to regional or subregional groups. INGA also assisted members and other countries to share GIFT and other farmed fish germplasm for research, use in national breeding programs, and for dissemination to farmers. From 1994 to 2003, INGA facilitated transfer of 133,494 tilapia germplasm for these purposes. All transfers were made under voluntary INGA protocols for biosafety, including quarantine, derived from the procedures adopted during initial acquisition of tilapia germplasm from Africa for development of the GIFT strain. The following protocols for the responsible and safe sharing of fish germplasm, including quarantine arrangements and environmental safeguards were revised in June 1995.
I. Exporting (transferring) Country
   • Provide information on:
     - Numbers
     - Origin and nomenclature (scientific, common, and local names) of stocks. Specify geographical location stock is collected. If stock originally came from another locality, it would be useful if name of the locality is provided. Specify breeding history, if possible.
     - Growth stage at time of export (eggs, yolk-sac larvae, post-larvae, fry, fingerlings)
     - Disease history
     - Parasite/predator history
     - Competition with other species. Include all possible aspects of competition such as food, habitat and reproduction, if available. If not, state as unknown.
     - Feeding habit
     - Reproductive characteristics (e.g., age at first maturity, spawning in stagnant water or running waters)
   • Certify freedom from prescribed parasites/pathogens and other biota
   • If possible, disinfect stock prior to shipment

II. Importing (receiving) country
   • Stocks should be imported as eggs or other early life history stages
   • Qualified personnel should examine shipments for freedom from prescribed pathogens/parasites and other biota. If diseases are identified, shipment should be destroyed and disposed of in an appropriate manner, unless effective treatment can be guaranteed.
   • Quarantine the imported fish for at least 30 days
   • Disinfect introduction upon arrival at quarantine unit if possible. If young fish are imported, give prophylactic bath
   • Upon arrival at quarantine unit, destroy or sterilise all water, packing materials, containers or other associated shipping materials.
   • Quarantine sites must be secure against escapes and discharges of water. Water must be safely disposed of.
   • If the quarantine unit suffers a disease outbreak that cannot be controlled, destroy diseased stocks and dispose of after sterilization in approved manner.
   • Monitor quality of water at the quarantine unit at regular intervals.
   • Continue periodic checks for introducible parasites and diseases.
   • Original imports should not be transferred to natural environments
   • Compile a list and periodically update known parasites and diseases and pathogens.
   • Advise exporter in case of unexpected occurrence of parasites or pathogens

Dissemination of GIFT and other tilapia germplasm occurred to Bangladesh, PRC, Côte d'Ivoire, Egypt, Fiji Islands, India, Indonesia, Kenya, Lao People’s Democratic Republic, Malaysia, Papua New Guinea, Thailand, and Vietnam.
INGA also facilitated formation of national networks in India, Indonesia, Malaysia, and the Philippines while contributing to strengthening of national institutes via regional workshops, training courses, staff exchanges, and research internships in quantitative genetics, broodstock management, GIFT breeding procedures, analysis of breeding data, and molecular genetics. Since 1995, 219 scientists and fisheries biologists from 28 countries in Asia, Africa, and Latin America have benefited from training conducted under the auspices of INGA. GIFT has also assisted member countries to develop national breeding programs. In Bangladesh, Fiji, Philippines, Thailand, and Vietnam, breeding programs and related genetics research are now based mainly, or exclusively on, GIFT or GIFT-derived strains and on the methods used originally to develop the GIFT strain. GIFT are also used extensively in research applied to developing tilapia farming in China, Indonesia, and Malaysia. INGA also facilitated implementation of ADB-financed regional TA for genetic improvement of farmed carps in Asia, following largely the same approaches as were used for the development and dissemination of the GIFT strain.

INGA members publish news on research advances and related developments and policy issues in the *WorldFish Center Quarterly, Naga*, in special publications and on the INGA web site. INGA has also facilitated expert consultations on key policy issues, for example on ecological risk assessment for the use of genetically improved fish and alien species in aquaculture. Strengths of the network are based primarily in broad-based, inclusive networking, a participatory mode of operation, and complementarity of skills of members. At present, the network has a membership of 13 countries from Asia, the Pacific and Africa and 12 advanced scientific institutions. Limited financial support and small human resources however, eventually constrained INGA operations. Financial assistance from the Norwegian Agency for Development Cooperation ended in December 2003 but the network continued to seek funding from other aid agencies. WorldFish Center currently supports INGA from its own core funds, but currently little information is available about INGA activities.

GFII

After completion of TA to develop and disseminate GIFT, the chief concern among participating institutes and funding agencies was how to keep intact the highly trained technical team in the Philippines that first developed GIFT to allow ongoing strain development and to widen access to GIFT and GIFT-related methods and training. There was also a need to provide for long-term management of the valuable gene bank of GIFT broodstock and cryopreserved sperm. All of the above were considered vital for continuation of the Philippine national tilapia breeding program, and for further development and use of GIFT and GIFT-related methods in other countries. Partner institutes that had developed and disseminated GIFT, in consultation with UNDP, decided that these provisions could best be met by establishing a new structure that would hasten commercialization of GIFT, taking into account the various assets, human resources, equipment, and GIFT germplasm available. The new structure was called GFII.

GFII was incorporated in the Philippines in 1997 as a non-stock, non-profit foundation to distribute GIFT on a commercial scale and to continue selective breeding efforts with GIFT. GFII personnel included senior executives from the Bureau of Fisheries and Aquatic Resources in the Philippines, Central Luzon State University (Philippines), and ICLARM, whose successors retain permanent ex-officio seats on the GFII Board of Trustees. In 1998, GFII occupied 8 hectares of land and facilities within the Center for Applied Fish Breeding and Genetics at Central Luzon State University. GFII took responsibility for managing the GIFT breeding nucleus and related germplasm, and employed highly trained Philippine technical staff who had participated in development of GIFT.
Initially, GFII financed its operations from fees charged to GIFT-accredited partner hatcheries, fees for improved germplasm and by providing technical services and training. In 1998, it entered into partnerships with seven privately owned tilapia hatcheries in nearby Philippine provinces via formal licensing arrangements. By the end of 2001, it had disseminated 522,700 GIFT broodstock to accredited private hatcheries.

In 1999, GFII drew up an agreement with GenoMar ASA (formerly Biosoft ASA) Norway, under which GFII and GenoMar ASA agreed to pursue collaborative research for further genetic improvement of GIFT in the Philippines, providing exclusive rights to GenoMar ASA for commercialization of new GIFT generations. Under this agreement, GFII contributed tilapia improved broodstock and other assets to GenoMar ASA in exchange for an equity position in GenoMar ASA. This commercial alliance was aimed at intensifying commercialization and dissemination of high-performing tilapia seed to fish farmers to meet demand for food fish from a growing local human population. GFII also retained its own GIFT broodstock to continue independent research and development (R&D). Under its agreement with GenoMar ASA, GFII can conduct its own independent R&D, provided that GenoMar ASA is informed of, and invited to, participate in such research. If GenoMar ASA declines to participate, GFII is free to seek other partners. New GIFT generations produced by GFII and commercialized by GenoMar ASA have been bred in GenoMar-accredited hatcheries in the Philippines and sold as GenoMar Supreme Tilapia™. GenoMar’s operations in production and marketing of GIFT-based fish seed have also been expanded to Bangladesh, the PRC, and Thailand.

International and Philippine national affiliations have positioned GFII as a major provider of training in tilapia genetic improvement and breed improvement programs. GFII collaborate with the WorldFish Center and INGA and train operators of tilapia hatcheries and staff from national institutes working in selective breeding, broodstock management, seed production, and sex reversal. Up until April 2004, GFII had provided training for individuals from the Asia-Pacific region as follows: Bangladesh, 19 trainees; Malaysia, 36; Papua New Guinea, 3; Philippines, 32; and Vietnam, 18. Over the same period, 15 trainees from INGA member countries in Africa (Côte d’Ivoire, Egypt, Ghana, Malawi, and South Africa) received training from GFII in selective breeding. In a broader context, GFII is also an associate member of INGA and is a partner in a multi-institute Tilapia Science Center in the Philippines, which has been the prime mover in establishing a national tilapia trade association (Philippine Tilapia, Inc.). GFII is also a major player involved with development of private-public partnerships for tilapia genetic improvement.
Appendix 2: Relevant information in relation to establishing a genetic improvement program of tilapia in East Africa

The 1999 Africa Regional Aquaculture Review, the 2004 report of the FAO WorldFish Center Workshop on Small-Scale Aquaculture in Sub-Saharan Africa and the 2005 FAO Expert Workshop on Regional Aquaculture Review all concluded that availability of fish seed is a major constraint on fish farming development in Africa. This constraint is in terms of both the quantity of seed available to producers as well as its relative quality.

Until recently, the seed problem was principally related to quantity available with many producers unable to gain access to sufficient seed regularly to fully exploit their farms. Most affected farms were small, integrated family operations of the sort currently categorized as “non-commercial”. For these farmers, management and investment levels are low and farming seed of improved strains would likely result in only marginal improvements to yield and/or would be excessively expensive even if they were available.

Over the past decade however, there has been a marked increase in investment in small, medium- and large-scale commercial aquaculture in many parts of Africa. Many aqua-businesses, of all scales in Africa, are now beginning to invest in better management, both human and biological. Such farms are starting to use better quality feeds and to maintain better water quality conditions in ponds and so are establishing culture environments where improved strains could in theory, approach their genetic potential. Nevertheless, most producers still do not have access to improved tilapia culture strains and little research is underway to develop improved indigenous catfish varieties.

Based on the best available technical information and the legitimate needs for improved food security and economic growth, it is clear that the rules and regulations governing access to, and use of improved aquaculture stocks are in need of revision. Increasing international competition is generating strong economic pressure to increase production while decreasing costs incurred by African fish farmers. Confronted with governmental reluctance to reconsider regulatory policy, illegal importation of alien species and strains is increasing, posing threats of disease and displacement of indigenous biodiversity. Left unresolved, these unregulated introductions pose serious and imminent threats to both the indigenous fauna and developing aquaculture industry. If these threats are to be mediated and for aquaculture to realize its potential to contribute to poverty alleviation, food security and economic growth in Africa, a solution will be needed in the short term.

The policy of the WorldFish Center not to disseminate the GIFT fish in Africa was based on a legitimate desire to protect for future generations of native people the vast natural tilapia biodiversity in Africa. The 2002 Nairobi meeting was convened to review the best available knowledge and to delineate the process via which decisions could be made regarding import and use of improved fish stocks. Since that time, an expanding food crisis in Africa, elucidation of Millennium Development Goals, growth of African commercial fish farming in association with potential of the industry to benefit from improved strains, awareness among producers of the key environmental issues and the ability of fish farmers to regulate themselves have altered the cost/benefit context prevailing at the time at which the Nairobi Declaration was framed. Aquaculture has expanded on the continent and many producers have overcome the basic technical constraints that would have rendered pointless and possibly dangerous an earlier introduction of, for example, the GIFT strain.

The Nairobi Declaration is a guideline for responsible use of improved fish strains, it should not be interpreted as either being for or against imports. Much of the debate about whether to import improved breeds is based on theoretical data, some limited empirical evidence and significant
negative impacts on local environments from culture of improved strains of fish already present in the watershed.

A cost-benefit analysis, maximizing positive benefits of improved genetic management while minimizing environmental risks will require a careful adherence to aquaculture best management practices. Introducing improved strains to a farm and then not feeding nutritionally-appropriate feeds or not applying best management practices is unlikely to improve growth rates or profitability significantly because improved fish will not perform well unless they are provided growing conditions to which they have been adapted during their development. Hatchery and grower certification would thus be a key element, both in ensuring that maximum social and economic value is achieved, and also so dissemination of improved strains is carefully regulated and monitored.

Likewise, just importing new strains for farming is at best, only likely to have local and short-term impacts if the technical capacity to manage and continue to improve the strains is not in place. This situation is currently generally lacking in Africa at both national and regional scales. A rational structure for the management of genetic resources, based on experience gained in other continents indicates a need for a centralized breeding program that can maintain, protect and continually improve farmed aquatic stocks. A structure such as the proposed East African Regional Fish Breeding Program could play this role over the short and medium terms.

There are strong commonalities among fish farmers across the target region in terms of constraints on farming growth. Critical mass (e.g. producers’ organizations) that can support development of hatcheries and other key elements in the production chain (e.g. quality feeds) is lacking in most EA countries. The proposed African Regional Fish Breeding Program could serve as a vehicle for maintaining and protecting regional aquaculture genetic resources. Existing producer information networks (e.g. AQUA-AFRICA) could serve as a virtual producers’ group, to support Msingi in facilitating the establishment of such a program.

Implementing this process is best based on a public-private partnership built on trust and appreciation of the potential mutual benefits for farms and the broader aquaculture community sector. Fish producers will also need to fully cooperate with research and regulatory bodies to ensure that best management practices are adhered to and that changes in biodiversity in areas affected by aquaculture are closely monitored and that any problems arising are addressed rapidly and effectively.