CIFA Occasional Paper No. 27 **CIFA/OP27**

ISSN 1014-2452

GENETIC MANAGEMENT OF AQUACULTURE STOCKS IN SUB-SAHARAN AFRICAN

Report of a Producers' Workshop
Accra, Ghana, 27 February-3 March 2006

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2006

PREPARATION OF THIS DOCUMENT

The FAO Inland Water Resources and Aquaculture Service, through the Fisheries Department group of the FAO Regional Office for Africa received financial support from the United Kingdom of Great Britain and Northern Ireland's Department for International Development and Technoserve to arrange a regional workshop on genetic resource management in sub-Saharan Africa, from 27 February to 3 March 2006. The workshop was designed and organized by FAO and the WorldFish Center, with Technoserve contracted for its implementation. This document is a report of the workshop including technical material presented. The document was prepared by Dr John Moehl, Regional aquaculture officer, FAO Regional Office for Africa, Dr Randall Brummett, Senior aquaculture scientist, WorldFish Center and Dr Raul Ponzoni, Research Scientist and project leader (genetics) aquaculture and genetic improvement, WorldFish Center.

ACKNOWLEDGEMENTS

The authors and organizers would like to thank the aquaculture producers who participated so actively in this workshop. This has been a rather unique opportunity to focus a regional technical workshop on producers and the enthusiasm with which they have embraced the topic and keenly contributed to the workshop's outcome have clearly demonstrated that such fora are most effective and should be repeated.

The authors and organizers also would like to express their thanks to the United Kingdom of Great Britain and Northern Ireland's Department for International Development and TechnoServe for their financial support and to TechnoServe for its excellent organization of the activity.

FOREWORD

The 1999 Africa Regional Aquaculture Review (CIFA OP24), the 2004 report of the FAO-WorldFish Center Workshop on Small-Scale Aquaculture in Sub-Saharan Africa: Revisiting the Aquaculture Target Group Paradigm (CIFA OP25) and the 2005 FAO Expert Workshop on Regional Aquaculture Review: Africa concluded that the availability of fish seed is one of the major constraints to aquaculture development in Africa. This constraint is in terms of both the quantity of seed available for producers as well as the quality of this seed.

Until recently, the seed barrier was principally with regard to the quantity available; many producers unable to gain access to enough seed to fully exploit their farms. Most of these 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 higher quality (e.g. improved strains) seed would likely manifest little if any enhancement in yield and/or would be excessively expensive if available.

However, within the past decade there has been a marked increase in investment in small-, medium- and large-scale commercial aquaculture in the Africa Region. These aqua-businesses, of all scales, are investing in good management; both human and biological. Such farms are using higher quality feeds, maintaining water quality and, in short, establishing conducive environments where improved strains could manifest their performance edge. Nevertheless, such firms do not formally have access to improved tilapia strains and little research is underway to develop similarly improved catfish varieties.

Given the growing competitiveness of national, intra regional and international markets, the central question for investors and would-be investors was how to have access to better performing culture organisms? The FAO Inland Water Resources and Aquaculture Service, through the Fisheries Department Group of the FAO Regional Office for Africa, convened a regional workshop that included private industry, government resource managers, representatives from environmental ministries and conservation groups to address these important issues within a broad context of conservation and development.

The workshop is also in response to articles of the FAO Code of Conduct for Responsible Fisheries[1] that requests that, "States should conserve genetic diversity and maintain integrity of aquatic communities and ecosystems by appropriate management", and, "... promote the use of appropriate procedures for the selection of brood stock and the production of eggs, larvae and fry" (Article 9.3), as well as the Nairobi Declaration (Appendix H) that provides a framework for responsible use of genetically improved seed for aquaculture.

[1] FAO,1995. Code of Conduct for Responsible Fisheries. FAO, Rome.

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EXECUTIVE SUMMARY

Aquaculture producers compete in a global market. While to date Africa's market share has been nearly inconsequential, there is rapidly expanding investment in aquaculture in Africa and the real potential that the region could become an important aqua-producer. However, while investment is growing and the quality of production inputs such as feeds is improving, producers do not have access to improved strains of culture organisms. Although a volume of data indicates that such improved strains can reach market size at least 50 percent faster than strains currently being raised by Africa's growers, the region does not formally have access to external supplies of these seeds nor is it close to developing its own improved strains of the chief aquaculture species: tilapia and catfish.

Within this context, the present workshop was organized to provide a forum for producers, fish geneticists, environmental regulators and other stakeholders to discuss issues surrounding the setting up of programmes to develop local improved varieties and the importation of existing improved strains. Participants received an overview of the technical issues revolving around genetic improvement; using this to draft a Producers' Position Statement encapsulating their point of view on the political and technical aspects relating to the culture of improved strains. This technical background also served as the foundation for elaborating three technical briefs on central genetics-related subjects. These briefs present the topics in succinct non-technical language for use by farm or hatchery managers as well as to inform technocrats and decision-makers.

Technical discussions and the Producers' Statement were subsequently used as the basis for reviewing selected literature, and analysing the scientific framework within which much of the previous decisions have been taken with respect to access to and use of improved strains. This scientific analysis is presented in the workshop report along with chapters discussing the role of the private sector, overall workshop conclusions and the way forward to keep the momentum that is building in the aquaculture sector in Africa.

Key recommendations made by producers:

1) Brood stock of the Genetically Improved Farmed Tilapia (GIFT) should be made available to African fish farmers as soon as possible, subject to inspection and certification as required by regulatory authorities and transfer approval from the WorldFish Center.

2) While in the short-term, improved fingerlings should be made available from extra-regional sources, this role should be transferred to the African Regional Fish Breeding Programme as soon as feasible.

3) A financing and technical implementation plan for the African Regional Fish Breeding Programme should be drawn up by FAO and the WorldFish Center and submitted to local and international donors for support.

4) Encourage and support national and regional research to domesticate suitable indigenous species for commercial aquaculture (e.g.*Clarias gariepinus*, *Oreochromis andersonii*).

5) Strengthen relationships between environmental regulation authorities and the commercial aquaculture sector to establish a mutually beneficial system of oversight and quality control.

6) Establish immediately a virtual African Commercial Fish Farmers Association to ensure producer inputs in the above processes and activities.

Corresponding conclusions and recommendation from the scientific analysis:

A. Regardless, the final decision whether to import existing improved breeds, encourage local hatcheries to breed their own local strains or do nothing, risks to the environment and the livelihoods of local people are unavoidable.

B. A careful cost/benefit analysis and risk assessment following the recommendations of the Nairobi Declaration on the Conservation of Aquatic Biodiversity and Use of Genetically Improved and Alien Species for Aquaculture in Africa made within the prevailing ecological and socio-economic contexts must be conducted.

C. Any importation should be approved only in conjunction with the putting in place of a program of monitoring and evaluation.

D. Research to identify genetic markers for GIFT or other cultured strains so as to track their dissemination for purposes of control, and sterilization techniques that could be used to eliminate most environmental risks arising from the spread of tilapia aquaculture should be seriously considered.

Overall workshop conclusions:

I. Aquaculture has a significant potential to contribute to poverty alleviation, food security and economic growth.

II. Based on the best available technical information and the legitimate needs for improved food security and economic growth, African fish producers are in general agreement that the rules and regulations governing access to, and use of improved aquaculture stocks are in need of revision.

III. The illegal importation of alien species and strains is increasing, posing threats to both the indigenous fauna and the aquaculture industry.

IV. There are strong commonalities among fish farmers in the region in terms of constraints to growth; however, critical mass (e.g. functional producers' organizations), which could support the development of hatchery and other key elements in the production chain (e.g. feeds) is lacking in most countries and some type of regional structure that could channel support services is clearly needed.

V. Implementation of this process should be based firmly on a public-private partnership built on trust and the appreciation of the potential mutual benefits for farms and the broader society of a prosperous and responsible aquaculture sector.

VI. Fish producers will have to fully cooperate with research and regulatory bodies to ensure that best management practices are being adhered to and that changes in biodiversity in areas affected by aquaculture are closely monitored and that any problems arising are rapidly and effectively addressed.

VII. The meeting acknowledges the commitment of the farmers and the obligations they have accepted in return for a revision of the policy surrounding the importance and use of genetically improved stocks (e.g. GIFT). It will be essential for international, national and regional agencies and natural resource managers to work closely with the fish farming industry.

1. Introduction

The workshop on Genetic Management of Aquaculture Stocks in Sub-Saharan Africa was organized by FAO, the WorldFish Center and TechnoServe. It was held at the Miklin Hotel in Accra, Ghana, from 27 February to 3 March 2005. The workshop was attended by 30 participants, including participants from five countries in the Africa region (Appendix A). The workshop agenda is presented in Appendix B.

Acknowledging the benefits incurred by the aquaculture sectors in other parts of the world where genetically improved culture organisms are reared, while such superior strains are presently not officially accessible to African producers, the objectives of the Workshop were to evaluate the options of developing unique improved strains for the Africa region vis-à-vis relaxing the controls on the importation of such organisms.

Producers were the target group of the workshop; twelve of the participants representing the private sector. In addition to producers and the organizers, other stakeholders included representatives from the Ghana Environmental Protection Agency along with representatives of the NGO community (i.e. Friends of the Earth, Conservations International and Opportunities Industrialisation Centers).

The workshop was structured so as to offer producers an opportunity to interact with a group of fish genetics experts; the experts served as resources in describing and analysing the issues involved in the potential introduction and use of improved culture organisms. In part, these interactions were aimed at developing user-friendly technical briefs on key genetic issues. These briefs are presented in Appendix C. Complementing the technical material contained in the briefs, a selected bibliography of genetics literature was also elaborated (Appendix D). A model for a regional coordinating unit is described in Appendix E while the outline of a regional genetic management programme is elaborated in Appendix F. Participant feedback is summarized in Appendix G. Additional background material including the Nairobi and Abuja Declarations and an example of considerations for brood stock management are presented in Appendixes H, I and J, respectively.

2. Background

Recent years have seen a rapid growth of aquaculture in several African countries as the private sector realizes fish farming is good business. Commercial farms (for profit) are now in production in, Angola, Cameroon, Congo, Ghana, Nigeria, Kenya, Madagascar, Malawi, Uganda and Zambia – to name a few countries experiencing an aquaculture renaissance. This private sector responsiveness, combined with growing concerns about national fish supply, has promoted increased political awareness of, and support for aquaculture.

Increased private sector investment is helping address the chronic constraints of a lack of good quality seed and feed. With the removal or mitigation of these constraints, yields are increasing and new limiting factors becoming more apparent; among these, the limited performance of many local culture species. Frustration over under performing fishes is exacerbated by readily available information concerning globally accessible high performance organisms such as the GIFT fish and "super" male.

The result of this frustration, in several cases, has been the unauthorized introduction of these improved fish 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 (February 2002). Producers are confronted with the possibility of achieving potentially significant production increases by using the top-of-the-line culture organism or of conforming to prevailing regulations and/or policies and using sub-standard local varieties. Profit potential can tip the scales and producers can opt to surreptitiously import better performing animals.

These clandestine or even overt introductions are facilitated by the difficulties Governments are experiencing in ensuring adherence to existing rules and policies. Borders are often porous and once a fish is introduced into a watershed, one must assume it exists throughout this drainage and probably throughout the country.

Within the context of a rapidly evolving aquaculture sub-sector, the 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 control of trans-boundary fish movements, other more practical options include the development of improved local species and the relaxation of controls of fish movements under specific circumstances to allow African producers access to globally available improved stocks.

Technical setting

Deterioration of genetic quality in cultured tilapia populations has been well documented and accounts for productivity losses of the order of 40 percent relative to wild stocks. Poor hatchery management, especially inbreeding, out-crossing (to wild fish that enter the system) and inadvertent selection are main causes. As aquaculture expands in Africa, pressure on government is increasing to either make improved indigenous species available for culture or allow the importation of alien species and/or strains. With the GIFT tilapia, which grows nearly twice as fast as the wild strains, already in widespread production in Asia, African producers will have no chance in the market unless they have access to improved seed.

To give African farmers realistic options to the importation of alien species, FAO and the WorldFish Center are initiating a series of regional activities in public-private partnership for fish genetic management and breeding aimed at:

1. increasing the capacity of the private sector in hatchery management;
2. increasing the capacity of government research and extension services to undertake selective breeding, and;
3. breeding a better-performing line of tilapia for grow-out

The Accra workshop served to initiate the project, develop practical training materials/ guidelines for use by the private sector and provide the basic technical training necessary to make such a partnership an effective tool. The workshop was comprised of two parts: 1) a review of existing documentation and training materials on fish genetic management and, 2) a review of the policies surrounding the importation and use of alien species.

Review of genetic management training materials

The existing literature on genetic management and selective breeding has been targeted at scientists and technicians and is of generally low value to the private sector hatchery managers who manage the vast majority of captive fish populations. To review the relevancy of existing training materials to the knowledge needs of Western African technology users, a group of hatchery managers and fish breeding technicians from Ghana, Nigeria and Cameroon will be brought together with key policy makers from the region. The key outputs will be: 1) improved knowledge of fish breeding and genetic management on the part of those private sector hatchery managers involved in the workshop and, 2) improved understanding of the constraints faced by the private sector on the part of public-sector researchers and technicians and, 3) a set of training materials for use by the private sector in fish genetic management with widespread applicability for use in the Western Africa region.

Review of regional genetic management policies

Since the 2002 Nairobi Declaration on the use of genetically improved and alien species for aquaculture and the conservation of aquatic biodiversity in Africa, aquaculture has expanded considerably, with increasing numbers of new investments across the continent. In effect, the Nairobi Declaration reinforced strict controls on the importation of alien populations. In the meantime, little progress has been made on the development of realistic alternatives. Following the 3-day training materials workshop, we propose an additional 2 days of round-table discussions between regional government representatives, private sector fish farmers and international agencies (FAO, WorldFish) 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 Relevant Policy instruments in light of the realities created by the growing aquaculture sector in Africa. The output of this consultation will be a set of guidelines for regional governments on how to address the growing demand for improved material for aquaculture.

3. Producers' position statement

The workshop scheduled time for producers to discuss among themselves the major issues relating to the use of improved stains and brood stock management. The following "Position Statement" was drafted by producers to reflect their joint point of view:

Whereas the international community has emphasized the importance of food security and economic development in their elaboration of the millennium development goals and the Abuja Declaration of the 2005 Fish for All Summit; and

Acknowledging that commercial aquaculture has demonstrated potential to supply high quality animal protein more efficiently than any other food production systems; and

Acknowledging that rural economic growth is heavily dependent upon the level of capital investment, job creation, and the development of secondary business opportunities through multiplier effects; and

Acknowledging that the long-term sustainability of aquaculture is related to the maintenance of a healthy aquatic environment, including conservation of genetic diversity; and

Acknowledging that there have been in the past unregulated and potentially harmful illegal introductions of alien fish strains and species; and

Acknowledging the intrinsic value of wild biodiversity in the conservation of genetic variability in protecting and conserving wild and domesticated populations; and

Acknowledging that unregulated dissemination of genetically improved fish could represent a risk to both the profitable operation of the aquaculture sector and the ecological integrity of natural fish faunas; and

Acknowledging that the growth of a competitive and commercially viable aquaculture sector is critically dependent upon the availability of high quality, fast-growing fingerlings; and

Acknowledging that fish farmers outside of Africa currently enjoy a large competitive advantage in domestic, regional and international markets due to their possession of, and easy access to, brood stock of African fish species improved through the process of traditional animal breeding[1]; and

Acknowledging that the maintenance of the genetic integrity of high performance, selectively bred fishes, and therefore their value in aquaculture, depends directly upon maintaining the highest standards of hatchery management and neither the physical nor human resources necessary are sufficiently available in much of Africa; and

Acknowledging the current need for external assistance in the establishment of necessary infrastructure, provision of training and fish breeding expertise; and

Acknowledging the importance of other (non-fish breeding) aquaculture best management practices, especially the use of feeds, in maximizing positive economic and food security impacts associated with access to new strains,

We, representatives of the African commercial fish farming community[2], propose 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.

Hearing the valid concerns of natural resource managers, the commercial fish farm operators commit themselves to a process assuring responsible business and farm management practices through submission to periodic inspection or other validation mechanisms to be implemented by lawfully delegated authorities.

We further undertake 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 the protection of aquatic resources and the use of improved fish strains. We further undertake 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 natural tilapia and catfish populations are quickly detected and that remedial actions are rapidly implemented.

We further propose to national and international bodies that they provide financial and technical support in the establishment of an African Regional Fish Breeding Program to include and be based at a state-of-the-art breeding complex(es) that could cater to the need for high-quality genetic management in the short term and continued long-term improvement of both tilapias and catfishes used in aquaculture. An important part of this program would be the establishment of a seed and commercial aquaculture certification

[2] A selected line and not what is commonly known as a genetically modified organism (GMO)

[3] Cameroon, Ghana, Nigeria, Uganda, Zimbabwe, *et al.* to be added pending circulation & approval.

system that could serve to guarantee the adoption of best management practices and regulate the distribution of fingerlings produced for aquaculture. It is further proposed that this programme be rapidly implemented within the next 12 months.

Specific recommendations from the producers

1) Brood stock of the Genetically Improved Farmed Tilapia (GIFT) should be made available to African fish farmers as soon as possible, subject to inspection and certification as required by regulatory authorities and transfer approval from The WorldFish Center.

2) While in the short-term, improved fingerlings should be made available from extra-regional sources, this role should be transferred to the African Regional Fish Breeding Programme as soon as feasible.

3) Given the importance of this topic to the growth of the sector, the technical seminar for the fourteenth Session of the Committee on the Inland Fisheries of Africa (CIFA 2006) should be devoted to strategies and methodologies for the use and development of improved aquaculture species in Africa.

4) CIFA should consider the establishment of an ad hoc Working Group on Aquaculture Genetics as an appropriate short-term tool to address the present issue and concentrate effort on its resolution.

5) FAO and the WorldFish Center should be requested to provide qualified technical assistance and training in breeding, genetic management and seed/farm certification as soon as possible. These suppliers of technical advice should be strongly committed to training of local partners, but also more directly implicated in project and programme execution than in the past.

6) A financing and technical implementation plan for the African Regional Fish Breeding Programme should be drawn up by FAO and the WorldFish Center and submitted to local and international donors for support.

7) That WorldFish Center scientists should immediately undertake, with local, regional and international partners, to identify and develop a research programme to address knowledge gaps.

8) Provide high quality, long-term technical assistance in genetic management to the region through the establishment of a regional producers umbrella support organization[1].

9) Encourage and support national and regional research to domesticate suitable indigenous species for commercial aquaculture (e.g., Clarias gariepinus, Oreochromis andersonii).

10) Strengthen relationships between environmental regulation authorities and the commercial aquaculture sector to establish a mutually beneficial system of oversight and quality control.

11) Establish immediately a virtual African Commercial Fish Farmers Association to ensure producer inputs in the above processes and activities.

4. Scientific context[5]

Africa is the original home of the entire world's tilapia species. Tilapias, however, have been introduced to over 90 countries outside of Africa, in many of which, they now form the basis of profitable aquaculture industries (Pullin *et al.*, 2001). As part of the domestication process that has produced all of the animal strains currently used in modern animal husbandry, and as the result of relatively new initiatives to selectively breed tilapias (e.g., the Genetically Improved Farmed Tilapia, GIFT), a number of the populations housed on fish farms outside of Africa have been improved, sometimes considerably so, as compared to the wild stocks from which they were derived. Whether these improved strains represent a threat to indigenous tilapia populations if they were to be reintroduced to Africa is the subject of this chapter. While much of the discussion refers specifically to tilapias, especially the GIFT fish, the general principles could apply to other species groups as well.

In actual fact, there is currently insufficient data available on tilapia ecology and/or genetic diversity to permit fully informed decision-making in regard to the potential negative impacts on wild African tilapia stocks of bringing back improved strains. However, the debate over the use of genetically modified fishes (either naturally through selective breeding or through transgenetic techniques) in general, has become global and includes a large number of case studies from, especially, Europe and North America. Whether or not these data are sufficient to adequately assess the risks involved in reintroducing tilapia strains modified outside of Africa to be brought back for purposes of commercial aquaculture is debatable.

Current African Hatchery Stocks

Tilapias are cultured to some degree in virtually all African countries. In each of these, captive populations have been established on farms and small-scale hatcheries. As a result of a combination of inbreeding, outbreeding, genetic drift and inadvertent (negative) selection, these populations have lost genetic diversity to the point where their growth performance is currently about 40 percent below that of wild stocks (Table 1).

[4] E.g., An inter-governmental organisation such as the Network of Aquaculture Centres in Asia (NACA) tentatively referred to as NACAf: Network of Aquaculture Centres of Africa (for further information on NACA, please see Annex E).

[5] This presentation of issues focuses on tilapia as the main culture species in Africa, and because, unlike for the other main African aquaculture species, improved strains of tilapia are currently available. Whether these arguments apply to other species depends upon their specific biology and ecology and genetic diversity.

Table 1. Documented erosion of genetic variability and growth performance among African hatchery tilapia populations.

- Introgression *O. macrochir* into *O. niloticus* reduced growth (Micha *et al.*, 1996)
- Backcrossing 3 generations of red hybrids lowers reproduction (Behrends, pers comm, 1985)
- Well-managed stock 12% better than small hatcheries (Morissens, Rognan and Dembele, 1996)
- Genetic variability down 50% in small hatchery stock (Morissens , Rognan and Dembele, 1996)
- Wild fish 43% more genetic variability than small hatcheries (Pouyaud and Agnese, 1996)
- 50% loss of genetic variability in small hatchery stocks (Agustin, Mather and Wibon, 1997)
- Wild populations better than African hatchery stocks (Eknath *et al.*, 1993)
- 70% loss of genetic variability among hatchery stocks (Ambali, Doyle and Cook, 1999)
- 50% less growth in hatchery Vs Lake Victoria stocks (Gregory pers comm., 2003)

In contrast, the GIFT fish, which has been maintained in captivity in Asia by professional geneticists and selectively bred since the late 1980s, has improved its growth rate in relation to most cultured stocks by at least 60 percent, and even 100 percent in some cases, now growing to over 800 g in 10 months under good conditions. Despite a certain loss in genetic diversity as a result of the selection process, rates of gain in performance per generation remain in excess of 10 percent.

Genetic introgression

The near certainty that cultured populations of indigenous species (e.g., caged Atlantic salmon in Europe) will escape and breed with wild fish is undeniable. Negative impacts of the accidental escape of cultured salmon and/or the purposeful introduction of hatchery stocks on wild runs has been repeatedly documented (Utter and Epifanio 2002; McGinnity *et al.*, 2003). The main cause of these declines has been through the process of genetic introgression, that is, the migration of genes from the captive population into the wild population through inter breeding. Mixing the genomes of captive fish that are specifically adapted to a hatchery environment with those that are specifically adapted to a particular river, or by increasing the relative percentage of genes from one subset of the wild populations into a river or lake, the overall degree of adaptation (i.e., fitness) of the wild population could be reduced (Ryman, 1991; McGinnity *et al.*, 2003). 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 (variability) of the fish population narrows, rendering the wild population vulnerable to environmental changes, one of which is the presence of large numbers of fish of other genotypes.

2. The relative sizes of the captive and wild populations. In cases where relatively small (i.e., <10, 000 individuals) wild fish populations which are highly adapted to a particular river or lake, are inundated by hundreds of thousands of stocked or escaped fish, such as is the case for many wild runs of Atlantic salmon, the consequences of the reduction in fitness can be catastrophic and ultimately result in the extinction of the wild genome, even when the total number of fish in the water body has increased (McGinnity *et al.,* 2003).

3. The degree of difference between the genomes of the wild and captive populations. The more distant the relationship between the introduced and wild genomes, the greater could be the theoretical reduction in fitness.

4. The goals of having captive and wild populations in the same stream. If preservation of the indigenous genome is considered of utmost importance, the increased number of fish in a particular water body as a result of stocking or escapes may be of less interest than the relative fitness of the population.

In the case of small, highly adapted (i.e. narrow genetic diversity) Atlantic salmon populations, the risk of introducing large numbers of less well adapted hatchery fish has been shown to reduce overall population fitness, at least in the short term (McGinnity *et al.*, 2003). On the other hand, long-term and large-scale releases of marine fish fingerlings in an effort to enhance relatively large and genetically diverse species such as cod, redfish and red sea bream have generally failed to produce any noticeable change in productivity, even in cases where effective breeding number[1] has been reduced (see Utter and Epifanio, 2002).

Introduction of new species

There are a very large number of examples of the disastrous consequences of introducing new species into both aquatic and terrestrial habitats in Africa and elsewhere. Some of these have been accidental (e.g. common carp into Lake Naivasha, water hyacinth into Lake Victoria) and some on purpose (e.g. Nile Perch and Nile Tilapia into Lake Victoria). A great many of these have proven costly in ecological, and quite often, in economic terms, and should not be repeated without either solid evidence that no negative consequences will be incurred, or in the face of compelling socio-economic and/or ecological necessity (e.g. the introduction of South American weevils to control water hyacinth in many African waterbodies). Examples from the order Pisces have been adequately reviewed by Lever (1996), the main concerns from the point of view of African fisheries managers being:

- Hybridization leading to genetic extinction; in places where *O. niloticus* will interbreed with important populations of indigenous species (e.g. *O. andersonii* in the upper Zambezi).
- Ecological displacement; competition for nesting sites with introduced *O. niloticus* and *Tilapia zilli* to Lake Victoria resulted in the displacement of *O. esculentus* and *O. variabilis*, respectively (Lowe-McConnell, 1988).

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[6] Effective breeding number (Ne) is the number of parents contributing genes to each subsequent generation.

- Introduction of diseases; this threat is obvious, real and pervasive and has cost fisheries and the society at large vast amounts of money in the repair or replacement of stocks and livelihoods devastated by alien microbial or parasite transmission to indigenous fish populations.

Table 2. Comparison of key biological and ecological traits of salmon & tilapias.

Salmon

- Top carnivores
- Relative few in number
- Generally narrow genetic bases
- Complex life history strategies; highly adapted to specific river systems
- Reproduce once and die

Tilapias

- Forage species feeding low on the food chain
- Large population sizes, even in small waterbodies
- Probably broad genetic bases,
- High levels of phenotypic plasticity; not specifically adapted to local habitats
- Reproduce at least three times per year

The risk of importing captive tilapia populations for African aquaculture

Although there are currently no documented cases of negative environmental impacts, *Oreochromis niloticus* is a weedy species that can survive in harsh conditions and could theoretically disrupt aquatic ecosystems were it to be introduced into pristine habitats, such as the rainforest rivers of West and Central Africa. The introduction of any strain of *O. niloticus* to places where it currently is not should therefore be undertaken with the utmost caution. As most captive populations eventually find their way into the wild, the transfer and culture of *O. niloticus* into new watersheds would be wisely avoided.

However, the principle concern among wildlife conservationists in regard to the importation of domesticated tilapias to Africa revolves around the danger of genetic introgression with wild populations which probably contain genetic diversity of important adaptive significance lacking in captive stocks. Nevertheless, there are substantial and important differences between Atlantic salmon, for which the majority of documented cases of genetic erosion have been published, and tilapias (Table 2).

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 might be significantly less than feared. Referring to the list of conditionalities presented above:

1. Tilapias are generalists and not normally adapted to specific waterbodies.

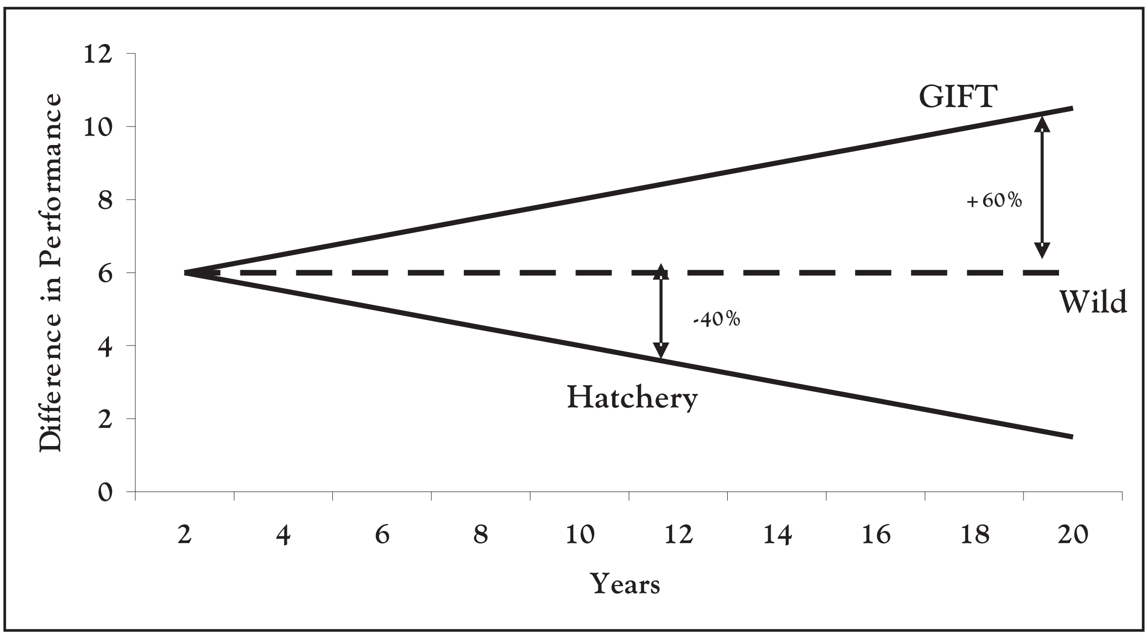
2. Wild tilapia populations are generally huge, in excess of millions of individuals, while escapes from aquaculture are minimized by farmers trying to protect their investments.

3. In terms of growth performance, hatchery populations of tilapia are 40 to 60 percent different than wild populations.

4. Food security and economic growth in impoverished communities are key concerns.

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

FIGURE 1. Theoretical trajectories of hatchery populations under various management regimes, relative to a hypothetical panmictic wild population from which they were derived.



At present, hatchery populations across Africa are substantially different from wild populations, mostly negatively. From the schematic figure below, it can be seen that the difference between the threat of introducing an improved strain, the GIFT in this 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 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 imported or not. It is just a matter of time.

There are two additional realities that should not be ignored when making decisions about conservation[1] of indigenous tilapia biodiversity in Africa:

[7] Pullin (2000) promotes the definition of "conservation" as "management and sustainable use" as opposed to "preservation" in which no use is envisaged.

1. *O. niloticus* has been repeatedly introduced into thousands of waterbodies throughout the continent since at least the 1940's. Many of these introductions have resulted in the establishment of feral populations.
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 the demise of their businesses, may well resort to such tactics in future.

Summary and recommendations

Regardless the final decision whether to import existing improved breeds, encourage local hatcheries to breed their own local strains or do nothing, risks to the environment and the livelihoods of local people are unavoidable. A careful cost/benefit analysis and risk assessment following the recommendations of the Nairobi Declaration on the Conservation of Aquatic Biodiversity and Use of Genetically Improved and Alien Species for Aquaculture in Africa made within the prevailing ecological and socio-economic contexts must be conducted and this is not easy considering the overall lack of hard scientific data. However, at least in the case of *O. niloticus,* the threat of major ecological damage resulting from the importation of improved strains for aquaculture in watersheds where it is either indigenous or feral seems relatively low.

To ensure that any problems arising are quickly identified and mediating measures rapidly put in place, and to collect sufficient information so that future such decisions are not made in a similar data vacuum, any importation should be approved only in conjunction with the putting in place of a program of monitoring and evaluation. The main elements of this program would include tracking and measuring rates of genetic introgression (probably based on the fixation index, Fst) and monitoring of fish catch trends (using Catch per Unit of Effort, CPUE). In addition, research to identify genetic markers for GIFT or other cultured strains so as to track their dissemination for purposes of control, and sterilization techniques that could be used to eliminate most environmental risks arising from the spread of tilapia aquaculture should be seriously considered.

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5. Role of the private sector

Aquaculture in Africa has significantly evolved in recent years. The view of integrated family fishponds contributing to household food security and community development has been expanded to include aquaculture as a for-profit business; businesses having micro-, small-, medium- and large (industrial) scales[1]. Current development approaches target aqua-businesses as the "motors" of aquaculture development with the aim of achieving the long-sought goals of enhanced food security and economic growth[2].

The strategies being presented in this approach have as their foundation the concentration of effort in high potential zones[3] with a reliance on private/public partnerships. High potential zones have the capacity to encompass a critical economic mass of producers or production; an area that represents a sufficiently high economic demand to be supplied by high quality inputs as well as having an adequately high level of production to be important actors in the marketplace.

This critical mass of producers presents a very different geographic picture from the scattered family ponds indicative of aquaculture programmes in the region a decade ago. The nature of their concentration, essential for economically viable operations, greatly facilitates monitoring and control. While the control of culture organisms in widely spread diminutive ponds sprinkled over the hinterland was acknowledged as being difficult at best and often impossible, regulation of clusters of production in an entirely different matter and well within the means of most regulatory agencies.

The present debate over the use of improved culture organisms is brought to the forefront by the private sector and, to a large extent, it will be their effective lobbying, based on

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8 Report of the FAO-WorldFish Center Workshop on Small-scale Aquaculture in Sub-Saharan Africa: Revising the Aquaculture Target Group Paradigm (CIFA/OP25, 2005)

9 National aquaculture strategies and strategic frameworks drafted for Cameroon, Zambia, Madagascar, Angola and Ghana.

10 High potential zones are areas where the bio-physical and socio-economic conditions are optimal for a specific aquaculture production system.

sound scientific analyses (*cf.* preceding chapter), that will convince governments to revise current regulations. This change, when affected, goes hand-in-hand with a commitment by the private sector to be responsible producers (*cf.* Chapter 3). The private sector must conscientiously commit itself to obey procedures and regulations relating to the use of improved species if this privilege, once obtained, is not to be revoked.

(Footnotes)

[1] Report of the FAO-WorldFish Center Workshop on Small-scale Aquaculture in Sub-Saharan Africa: Revising the Aquaculture Target Group Paradigm (CIFA/OP25, 2005)

[2] National aquaculture strategies and strategic frameworks drafted for Cameroon, Zambia, Madagascar, Angola and Ghana.

[3] High potential zones are areas where the bio-physical and socio-economic conditions are optimal for a specific aquaculture production system.

6. Conclusions

Based on the best available technical information and the legitimate needs for improved food security and economic growth, African fish producers are in general agreement 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, the 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 the 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, a solution is needed in the short term.

The policy of the WorldFish Center not to disseminate the GIFT fish in Africa is based on a legitimate desire to protect for future generations the vast tilapia biodiversity of Africa. The 2002 Nairobi meeting was convened to review the best available knowledge and the Declaration was elaborated to delineate the process through which decisions could be made regarding the importation and use of improved fish stocks. Since that time, the expanding food crisis in Africa, the elucidation of the Millennium Development Goals, the growth of African commercial fish farming and the potential of the industry to benefit from improved strains, the 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 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 dangerous an earlier introduction of, for example, the Genetically Improved Farmed Tilapia (GIFT).

The Nairobi Declaration is a guideline for the responsible use of improved fish strains; it should not be interpreted as either for or against importation. Much of the debate on the importation of improved breeds is based on theoretical data, some empirical evidence for a certain cases, significant negative environmental impacts from the culture of improved strains of fish species already present in the watershed, are unlikely.

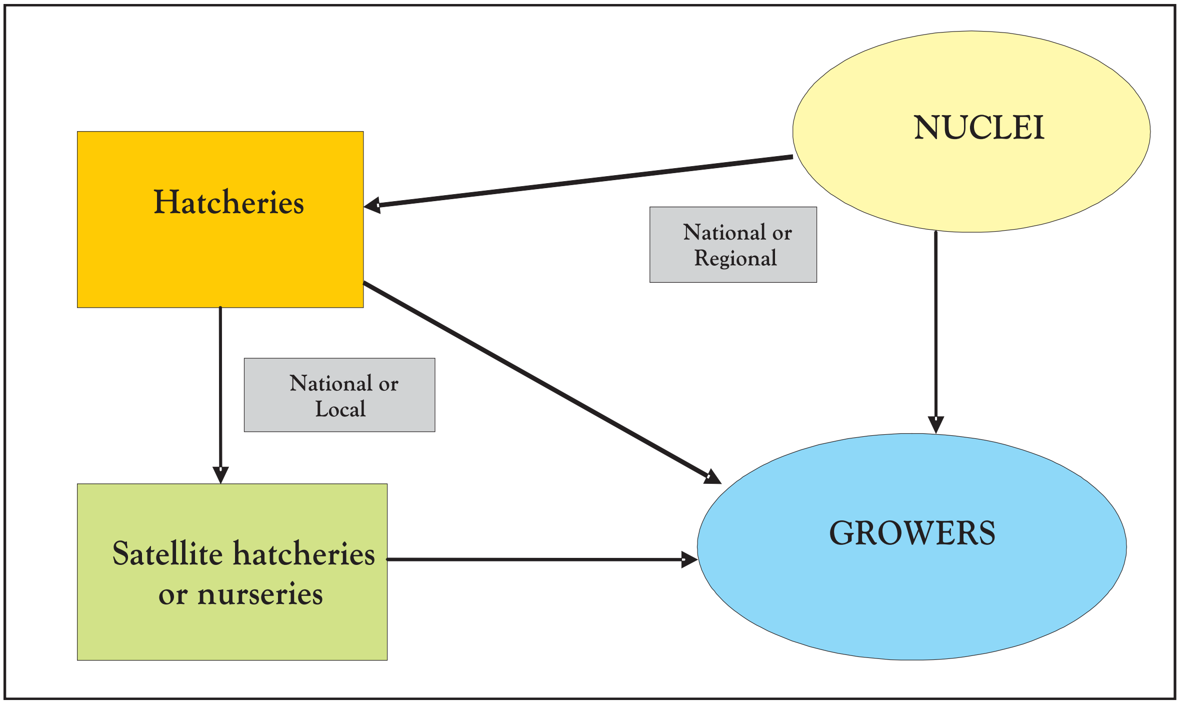

FIGURE 2. Schematic representation of an improved breeding programme with the selection taking place at "nuclei" which are specially staffed and maintained facilities devoted to improved breeding; often operated in some form of public/private partnership. Hatcheries are private sector businesses which purchase improved brood stock from the nuclei and reproduce these to produce seed either to sell directly to growers or to satellite hatcheries or nurseries which are located closer to clusters of growers and facilitate seed distribution.

National policy and regulatory instruments are currently inadequate and fail to clearly delineate responsibilities for addressing these issues. In many countries, critical mass to support political initiatives is lacking or narrowly focused. National aquaculture strategic frameworks could provide the necessary guidelines and should be considered for all countries. As part of these, multi disciplinary fora representing key stakeholders (e.g. producers, government, environmentalists and civil society, *inter alia*) could serve to clarify the main issues and move toward a rational compromise.

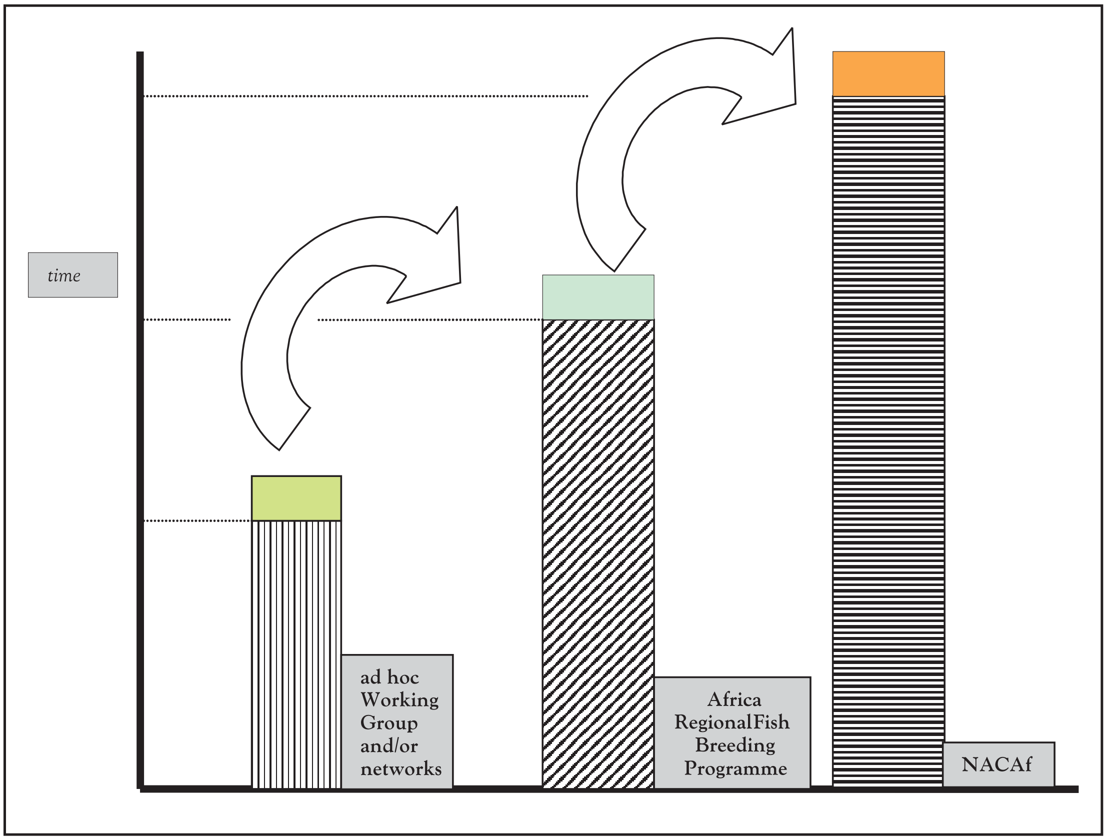

FIGURE 3. Possible evolution of an African Regional Breeding Programme based on extra budgetary and extra regional support. In the immediate and short-term, stakeholders can establish a virtual network to exchange views and lobby for support. This could be complemented by an ad hoc Working Group on this subject if so approved by CIFA. These short-term actions would facilitate the design and implementation of a regional programme which would, in the medium-term, blend into the functions of NACAf.

In this 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 new strains on a farm that does not use feeds and other modern aquaculture technology will do nothing to improve growth rates and profitability. Hatchery and grower certification would thus be a key element, both in insuring that maximum social and economic value is achieved, and that the dissemination of improved strains is carefully regulated and monitored.

Likewise, the simple importation of new strains will have only local and short-term impact if the technical capacity to manage and continue to improve these strains is not in place. This is currently lacking at the national or even regional levels. A rational structure for the management of genetic resources, based on experience gained on all other continents indicates the need for a centralized breeding program could maintain, protect and continually improve aquaculture stocks (Figure 2). A structure such as the proposed African Regional Fish Breeding Programme could play this role in the short to medium terms.

There are strong commonalities among fish farmers in the region in terms of constraints to growth. However, critical mass (e.g. functional producers' organizations), which could support the development of hatchery and other key elements in the production chain (e.g. feeds) is lacking in most countries. Some type of regional structure that could channel support services is clearly necessitated. In the medium-term, NACAf could provide the framework needed for Africa. More immediately, the proposed African Regional Fish Breeding Programme could serve as a vehicle for the maintenance and protection of aquaculture genetic resources. Existing producer information networks (e.g. AQUA-AFRICA) could serve as a virtual producers' group, facilitating the establishment of such a programme (Figure 3).

Implementation of this process should be based firmly on a public-private partnership built on trust and the appreciation of the potential mutual benefits for farms and the broader society of a prosperous and responsible aquaculture sector, and will form a key element in the evolution of the above described facilities and institutions. Fish producers will have to fully cooperate with research and regulatory bodies to ensure that best management practices are being adhered to and that changes in biodiversity in areas affected by aquaculture are closely monitored and that any problems arising are rapidly and effectively addressed.

The meeting acknowledges the commitment of the farmers and the obligations they have accepted in return for a revision of the policy surrounding the important and use of genetically improved stocks (e.g. GIFT). It will be essential for international, national and regional agencies and natural resource managers to work closely with the fish farming industry. The above-described high standards that the aquaculture community has elaborated for itself will facilitate this partnership.

7. Way forward

Action is required. This must take place simultaneously at several levels and in several places. The private sector needs to further educate itself about the scientific bases for the arguments against the introduction of improved species, while enhancing communications and networking among its members. Concurrently, there must be external assistance to the sector and the region to address this issue.

External support can be channelled through CIFA in the immediate term; using this subject as the topic for its next technical seminar as well as considering the establishment of an ad hoc Working Group as recommended by producers. At the same time, more substantial support for the Africa Regional Fish Breeding Programme (Appendix F) needs to be procured and the programme implemented. This Programme would merge into NACAf as shown in Figure 3 to ensure long term monitoring of the Region's genetic resources.

National and sub-regional action is also required. As this issue is basically a question at watershed level, it is critical to put in place the necessary mechanisms to monitor the movement and quality of culture organisms. This involves a series of permits and certificates. Referring to Figure 2, nuclei need to be certified both in terms of the technical quality and management of their brood-stock-producing techniques and with regard to the quality of the brood animals they sell. This same type of certification procedure needs to be applied to core hatcheries as well as satellites or nurseries. Growers must be both licensed and authorized to raise improved strains; this authorization based on a composite of factors including overall management level, containment, and technical capacity.

The preceding discussion describes necessary action; often action predicated on external human and financial resources. However, the availability of these resources is beyond the control of the Workshop participants and often subject to the vagaries of national and regional politics. In spite of the growing political will to support commercially viable aquaculture for all its inherent benefits, this may well, in and of itself, not be sufficient to move the public sector agenda forward.

Throughout the Workshop, the farmers, the Workshop's principal focal group, have stressed the urgency in taking tangible steps toward addressing this complex issue of the use of external improved strains. Through their Position Paper (Chapter 3), producers have made a strong statement as to their readiness to establish real and functional public/private partnerships. Nonetheless, some segments of the private sector have also demonstrated their understanding of the adage "time waits for no one". Improved or reportedly-improved organisms have illegally been imported into a number of countries; moved from watershed to watershed. The uncontrolled and unregulated introduction of such organisms will only stop when the private sector is confident they have access to better-performing strains through official channels. The urgency is real. If prompt public sector action is not initiated, illegal activities will increase – perhaps to a point where formal action will become meaningless.

APPENDIX A

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APPENDIX B.

AGENDA

Day 1/27 February 2006

0730	-	0830	Registration[11]
0830	-	0930	Introduction
0930	-	1100	Producers group meeting
1100	-	1230	Presentation of issues by group chairs and discussion
1230	-	1400	Lunch
1400	-	1430	Finalization of list of issues
1430	-	1800	Principles of Genetics Management in Aquaculture

Day 2/28 February 2006

0830	-	0930	Selection of brief topics
0930	-	1230	"Writeshop" on selected brief topics
1230	-	1400	Lunch
1400	-	1700	Group review and discussion of briefs

Day 3/1 March 2006

0830	-	1230	Producer forum and discussion
1230	-	1400	Lunch
1400	-	1630	Preparation of Position Statement

Day 4/2 March 2006

0830	-	1030	Review Producers' Statement and recommendations
1030	-	1230	Discussions with genetics panel
1230	-	1400	Lunch
1400	-	1730	Panel discussions on biodiversity issues

Day 5/3 March 2006

0830	-	1100	Free
1100	-	1130	Distribution of provisional conclusions
1130	-	1330	Final discussion and approval of conclusions
1330	-	1500	Lunch

11 Participants received a set of background documentation on CDs at the time of registration along with photocopies of selected reference documents. The Producer Statement with its recommendations as well as the workshop conclusions were distributed on CD to participants at the end of the workshop.

APPENDIX C.

TECHNICAL BRIEFS

I. Selective breeding methods

INTRODUCTION

Aquaculture is predicted to play a major and ever increasing role in meeting human needs for protein. In terrestrial animal and plant species genetic improvement programs have made a substantial contribution to productivity and viability. By contrast, most aquaculture stocks in current use in developing countries are genetically similar or inferior to wild, undomesticated stocks. Hence, there is ample justification for the planning, design and implementation of genetic improvement programmes for aquatic animal species. A range of methods of varying complexity is available for selection purposes, but their suitability for different circumstances is not always clear. In this paper we briefly present the main selection methods that have been used or advocated, and discuss their virtues and shortcomings. When possible, we make reference to practical examples of their application.

SELECTION APPROACHES

General

We present the different selection approaches in increasing order of complexity, beginning with the simplest one. In each case, we refer to specific requirements that may constitute a limitation for their implementation in developing countries. Note that we assume that there is genetic variation for the trait(s) of interest in the population undergoing selection and that it does not suffer from problems (e.g. bottlenecks, inbreeding) created by earlier genetic mismanagement. Such problems could undermine the effectiveness of any selection programme.

Individual or mass selection.

The terms "individual selection" and "mass selection" are often used interchangeably, and they refer to selection solely based on the individual's phenotype. It has been a common strategy with fish because of its simplicity. It does not require individual identification or the maintenance of pedigree records, hence it may be considered the least costly method. In principle, it can produce rapid improvement if the heritability of the trait(s) under selection is high. Under those circumstances, however, there is risk of inbreeding due to inadvertent selection of progeny from few parents producing the best offspring, especially if progeny groups are large. For growth rate and morphological traits (easily assessed, expressed in both sexes) it can be quite suitable. By contrast, individual selection is not suitable for traits that require slaughter of the animals (e.g. carcase and flesh quality traits) or challenge of some sort (e.g. selection for salinity tolerance or for disease resistance).

The general conclusion is that mass selection is not a suitable method to be applied at the nucleus level unless measures can be taken to control inbreeding. It may be used, however, at the hatchery level in cases in which the stock is frequently being refreshed with stock from the nucleus and any inbreeding is undone in that way.

Selection within cohorts and exchange of breeders

In view of the genetic deterioration often taking place in hatcheries due to poor brood stock management, among other measures to remedy the situation, it has been suggested that brood stock could be arbitrarily divided into several groups. Mating could then be performed between individuals from the different groups on a rotational basis to avoid inbreeding.

As an example we will describe the mating design used for weight selection in redclaw crayfish (*Cherax quadricarinatus*). The population was divided into cohorts, namely, groups sampled from a previously established foundation population. A selection line was created, consisting of 20 cohorts, where each cohort had 15 female and 10 male foundation parents. A control line of eight cohorts of the same size was also established. One hundred individuals were measured per cohort. Offspring of cohorts were hatched and grown in separate pens within a pond. At harvest time individuals of the heaviest weight in each cohort were chosen as parents of the next generation in the selection line, whereas individuals of average weight were chosen in the control line. In either case, selection was based on the difference between the harvest weight of an individual and its cohort mean. This within cohort selection aims to eliminate the environmental effect of cohorts on growth differences among individuals. The same number of individuals was selected from each cohort. Animals selected in one cohort were mated with those selected in another one to avoid mating related animals. After four generations of selection harvest weight in the selection line was 1.25 times greater than in the control line.

Note that in this method although the exact number of parents contributing to the next generation is not known the rate of inbreeding can be calculated for the worst case, that is, that only one pair per cohort left offspring. Generally, inbreeding at generation t, would be calculated as:

$F_t = 1 - (1 - F)^t$ where $F = 1/(8f) + 1/(8m)$

where f and m are the number of females and males leaving progeny in each generation. With only one pair leaving progeny per cohort the equation becomes:

$F = 1/(8c) + 1/(8c) = 1/4c$ where c is the number of cohorts. We may then write:

$F_t = 1 - (1 - 1/4c)^t$

and we can use this equation to predict the maximum inbreeding after t generations. By designing the selection program in such a way that even in the case that only one pair from each cohort produced progeny the inbreeding rate was not excessive, then we would be able to ensure that we would not run into problems due to inbreeding. With regards to the exchange of breeders between cohorts, this could be achieved by shifting the males born in one cohort to another one in a pattern that avoids inbreeding. In practice, we have found that, in contrast to single pair matings, selection within cohorts with exchange of breeders between cohorts following a prescribed pattern is a feasible design even with limited resources. Field personnel feel comfortable with it, and will thus rigorously adhere to the instructions provided.

Within family selection

The method requires identification of the families. This may be achieved by maintaining them in separate tanks, cages, hapas or any other means of containment, without necessarily tagging the fish. The criterion of selection is the deviation of each individual from the mean of the family to which it belongs. Within family selection is especially advantageous when there is a large component of environmental variance common to members of the same family. Full sib groups reared in unreplicated hapas or any other form of containment fall into this category. Under such circumstances selection between families would be misleading from a genetic viewpoint because of the confounding between genetic merit and common environmental effects. The method can make very effective use of facilities. If replacements are chosen so that every family contributes the same number of individuals to the next generation (e.g. choose one female and one male from each family) the effective population size twice the actual. However, not all the additive genetic variance is available for selection, only a fraction r will be available, where r is the coefficient of relationship among the family relatives in question (i.e. 0.5 and 0.25 for full and half sibs, respectively). For example, if for a particular trait the heritability in the population is 0.2 and the families are full sib groups, then the within family heritability is $h^2_w = 0.11$. The lower within family heritability can be compensated for by the high within family selection intensity that can be applied without increasing the rate of inbreeding. The selection intensity within families will be limited only by the number of individuals tested per family. The number of families involved in the program will determine the lower limit of inbreeding, which can easily be controlled by applying a rotational mating system such as that earlier suggested for selection within cohorts.

The use of within family selection was successfully applied in the selection program that resulted in an improved Tilapia strain developed in the Philippines by the Freshwater Aquaculture Center (FAC) of Central Luzon State University. The strain is known by a variety of names, FAC-selected, FaST, and IDRC strain (in recognition of the support received from the International Development Research Center of Canada). The selection line started from a base population combining four strains of Tilapia, namely, Israel, Singapore, Taiwan and a "FAC" strain available at the time. Nineteen full sib groups were established, and the basis of selection was body weight at 16 weeks of age. The heaviest male from a given family was mated to the two heaviest females of another family to avoid inbreeding. After 12 generations of selection the genetic gain in body weight has been estimated at 12.4 percent per generation. All the selection program was conducted (from spawning to selection) in outdoor concrete tanks, but the strain also performed well in hapas and ponds. Within family selection was easy to manage, and taking care of inbreeding by means of a rotational mating posed no difficulties. The method reduces the need for tagging large numbers of individuals.

Combined selection

We use the term "combined" selection' in a broad sense, meaning selection that is based on individual information as well as on information coming from relatives (e.g. full and half sibs, progeny). In this case all of the additive genetic variance is available for selection and the use of information from relatives increases the accuracy of the estimation of breeding values. Furthermore, relatives' records can be used to estimate breeding values for traits that require slaughter of the animals (i.e. carcase and flesh quality traits) or that entail a risky challenge (i.e. disease resistance, tolerance to some environmental component). This is not possible with the other methods. Earlier work with fish used selection index theory to combine individual, full sib and half sib information. A selection index can be very useful in combining such information, but the approach has limitations. Better methods are now available that overcome those limitations, and they are generally known as Best Linear Unbiased Prediction (BLUP) procedures. In the case of aquaculture, all systematic effects (e.g. batch, sex, production environment, age variation) associated with traits of interest can be accounted for in the model fitted to the data. The maternal and common environmental effects due to separate rearing of full-sib families before tagging can also be separated effectively from the additive genetic variance. One particular advantage of BLUP procedures is that genetic gain can be estimated from the mean of the estimated breeding values in each year or generation of selection provided there are genetic links. A drawback of BLUP selection is that it also results in higher level of inbreeding, especially for lowly heritable traits, than individual selection. This is because BLUP uses family information, leading to co-selection of relatives. Hence, optimal genetic contribution theory should be used in order to maximize genetic gain while controlling the rate of inbreeding.

In order to use combined selection, identifiable families have to be produced. This is usually achieved by pair mating or by external fertilization of ova and sperm of known parental origin. The progeny of the different families must be marked in some way so that they can be communally stocked and tested for genetic evaluation purposes. Preferably, all the individuals to be tested should have a unique identification, and the pedigree will take care of all family relations. Aquatic animals are generally very small at spawning. They are kept in their family (usually full sib) groups until they are large enough to be tagged. This often results in an appreciable common environmental effect in traits such as growth rate. Tagging itself is an issue. The most commonly used tags with fish are Floy Tags ® and PIT (passive integrated transponder) tags, the latter being about five times more expensive than the former, but far superior in terms of retention rate. With Floy Tags we have lost up to 60 percent of the tags in some groups due fragility of the thread that holds the plastic tag. In the hands of unskilled staff the combined effects of poor reproductive rates, large common environmental effects, and high tag losses can negate the theoretical virtues of the approach. The potential advantages of combined selection cannot be disputed, but before embarking upon it, one must be sure that the physical and human resources at hand are adequate for the tasks that will have to be undertaken.

Three documented examples of the successful application of combined selection to the improvement of fish in developing countries will be cited here (in all cases growth rate was the main focus of selection): (i) the GIFT project in Philippines, which reported genetic gains of 12 to 17 percent per generation in Nile Tilapia, over five generations; (ii) the Jayanti Rohu (*Labeo rohita*) selective breeding project in India, which reported a genetic gain of 17 percent per generation over five generations; and (iii) the selection project of a Malawian indigenous Tilapia, *Oreochromis shiranus*, where the accumulated gain over two generations was 13 percent. GIFT and Jayanti Rohu have been tested extensively on farm and proven to outperform other strains used by farmers. The GIFT and FaST strains have very similar growth performance, but GIFT has shown greater survival rate, possibly due to the broader genetic basis in the population originally assembled and to the greater effective population size relative to FaST. Because the program with *O. shiranus* is still in its early stages, the strain has not yet been tested extensively on farm.

These three programs (GIFT, Jayanti Rohu, *O. shiranus*) have a number of features in common: (i) they all started with the assembly of a base population drawn from different sources in order to capture genetic variation; (ii) controlled matings of identified females to identified males were conducted and complete pedigrees were maintained; (iii) full sib groups were kept together until tagging; (iv) approximately, 50 to 200 fish per full sib group were tagged and destined to communal rearing in a range of production environments in order to estimate genotype by environment interactions. In the case of GIFT and Jayanti Rohu a selection index combining individual, full sib and half sib information was used to rank individuals on genetic merit, whereas BLUP breeding values were estimated in *O. shiranus*. BLUP procedures are also used in the selection of GIFT in the population that was transferred to Malaysia. The sound design coupled with rigorous conduct and analysis accounts for the gains achieved in these programmes. Furthermore, data sets of this nature, developed over a number of generations, provide great research opportunities in the area of estimation of phenotypic and genetic parameters, as well as of environmental effects. As a by-product of the genetic improvement program, opportunities for local staff capacity building are created around it. If captured, these opportunities can result in the training of staff to a level that enables them to independently plan and conduct genetic improvement programs. Note that the amount of information that can be extracted from a pedigreed population is much greater than from a non-pedigreed one. This general model, packaged in what has been called "GIFT Technology" has been advocated by the WorldFish Center for implementation in several developing countries.

CONCLUDING REMARKS

A rigorous comparison of different methods based on published evidence is not possible. In practice the outcome of a program will be affected by many factors other than the selection method itself. When planning a new program in a developing country, a way of approaching the problem could be to begin thinking about and outlining the most complete one (i.e. full pedigrees and BLUP estimates), and to simplify it gradually until it becomes feasible with the available resources, working backwards through the methods we presented. The final decision before implementation will be a matter of judgment. For instance, a national program developed with a NAR would most likely have a larger component of capacity building than one for a commercial operator. In any case, one should ensure that the program is manageable within the limits of the available physical and human resources, and that it has a high probability of continuing beyond project duration. Starting with a population with ample genetic variation is a trademark of successful fish genetic improvement programmes. Although this in itself is not a sufficient condition for success, it is indeed a necessary condition. Sophisticated designs and genetic evaluation procedures are no substitute or remedy for a genetically deteriorated base population. The failure of some attempts to achieve genetic improvement with aquatic animals may have been due more to weaknesses in the base population than to the selection method utilized. Irrespective of the method of choice, continued genetic improvement will hinge upon the adequate balance between high selection intensity and the maintenance of low inbreeding rate.

II. Genetic management in aquaculture: effective breeding number

Effective Breeding Number (Ne) is the number of parent fish that spawn and leave offspring. In fish hatchery stocks, this means the number of broodfish that are reproduced each year or reproduction cycle. If all males and females spawn, Ne is equal to the number of males and females added together. However, hatchery managers often use unequal numbers of males and females, or in certain cases, not all the males or females spawn, reducing Ne. The effective breeding number can be calculated by the following formula:

$$Ne = \frac{4 \text{ x (number of females x number of males)}}{4 \text{ (number of females + number of females)}}$$

Why is Ne important to fish farmers?

Effective breeding number is directly related to the amount of genetic diversity in the hatchery. If the number of broodfish is large Ne > 100), the amount of diversity is large, and *vice versa*. Diversity is related to inbreeding. When fish are inbred, they are less resistant to disease, have fewer offspring, grow less well and often have physical deformities. The rule of thumb in determining the effective breeding number needed in the hatchery is that inbreeding should not exceed 1 percent. Inbreeding is calculated by the following formula:

$$\text{Inbreeding (\%)} = \frac{1}{2 \text{ x Ne}} \text{ x } 100$$

Ne and diversity are also important if the hatchery stock is to be improved through selective breeding. When Ne is low (Ne < 80), the genetic diversity is also too low to permit successful breeding.

Imagine, for example, that a farmer is spawning tilapia. If the hatchery is managed according to sound principles of genetic management, there will be at least 40 females and 40 males in each spawning. If each parent contributes equally to the next generation, then:

$$Ne = \frac{4 \text{ (40 x 40)}}{(40 + 40)} = 80 \qquad \text{Inbreeding} = \frac{1}{2 * 80} \text{ x } 100 = 0.6\%$$

An Ne of 80 is enough to keep approximately 90% of the genetic diversity of the original stock in the hatchery stock and the inbreeding below 1%. This stock is healthy and will remain so as long the farmer continues to follow good genetic management. However, if the farmer uses only 10 pairs, then:

$$Ne = \frac{4 \text{ (10 x 10)}}{(10 + 10)} = 20 \qquad \text{Inbreeding} = \frac{1}{2 * 20} \text{ x } 100 = 2.5\%$$

In the resulting stock, genetic diversity has been lost and there is an increased risk of birth defects and a lower potential from selective breed. If the farmer uses an unequal sex ratio of 3 females per male as is often the case with tilapias, then:

$$Ne = \frac{4 \text{ (30 x 10)}}{(30 + 10)} = 30 \qquad \text{Inbreeding} = \frac{1}{2 * 30} \text{ x } 100 = 1.6\%$$

Even though the farmer used more broodfish than the previous example, inbreeding is still unacceptably high and genetic diversity is still being lost. When left on their own, tilapias and a number of other fishes do not spawn in equal numbers. In ponds, for example, the more dominant males will fertilize most of the females. On average, 25 percent of the males will fertilize almost all of the females so that:

$$Ne = \frac{4\ (30 \times 10/4)}{(30 + 10/4)} = 9.2 \qquad \text{Inbreeding} = \frac{1}{2 * 9.2} \times 100 = 5.4\%$$

Unfortunately for their health, growth rate and general condition, this common spawning system is damaging the genetic diversity of the hatchery stock.

Managing Ne

There are two major considerations in keeping the Ne high enough so that the fish stock remains healthy and fast growing:

1. Be sure to start the hatchery stock with more than 40 pairs of broodfish and get extras in case some die.
2. Be sure all of the fish spawn. For tilapias, it is necessary to put each pair alone in a tank or hapa to give every male a chance to spawn.
3. Spawn males and females in equal numbers. Contrary to popular belief, this produces just as many fingerlings as unequal numbers, while reducing the risk of inbreeding.

There is often a temptation, particularly with fish that have a lot of eggs, to spawn just enough broodfish to stock ponds for grow-out. Do not be tempted! If you have too many eggs or fry, simply take an equal number from each pair and sell the rest.

III. Inbreeding

DEFINITION : What is inbreeding in a fish hatchery?

It is the crossing of closely related males and females (fishes) of an organism as for example family members of fishes in a hatchery where a hatchery operator continuously produce fry from the same fishes and their offsprings.

Why should Inbreeding be an issue for a fish hatchery Operator to consider?

Because closely related organisms tend to habour similar "bad" recessive genes which would increase in frequency in their offspring that will result in reduction in fitness of the offspring. However, every hatchery operator should aim at avoiding production of fishes with less fitness compared to the parents.

Information from commercial hatcheries in Africa that have unintentionally inbred their stocks has reported of stunted growth and low survival of the offsprings.

Management practices to avoid Inbreeding.

The major operation of a hatchery is the propagation of material obtained from breeding centres without lowering fitness or quality of offsprings. However, unintended inbreeding could take place leading to the lowering of fish culture performance. To avoid the situation, the following are recommended:

1. Give identity to parent stock as groups or individuals to be able to decide on the pairing of parents to generate offspring.
2. Where hatcheries are using improved parent stocks, periodic addition of stock material from breeding stations should be practiced.

3. Where unselected or wild stocks are used in hatcheries to generate fingerlings, as is the situation in most non-commercial hatcheries in Africa, periodic addition of material from the wild is recommended.

4. Use large number of parent individuals (e.g. 200 or more parents) to respond to having an effective population size (Ne).

5. For Tilapias, avoid producing fingerlings using several parents together as is usually practiced in mass fry production with the assumption that all males would contribute to the gene pool of the offsprings.

6. Rotate male and female parents for fry production.

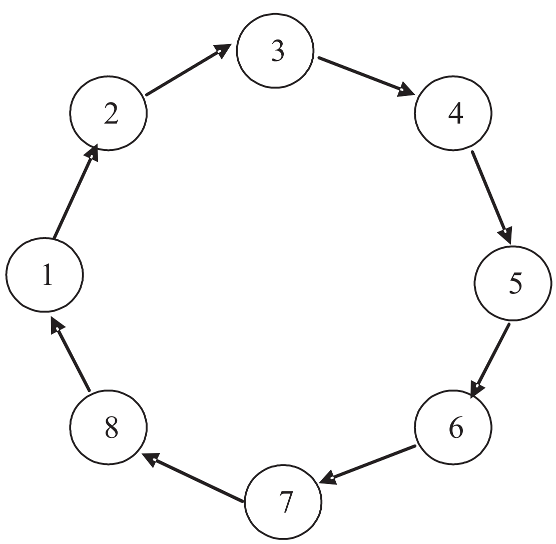
7. Use of hapas and/or tank for fry production should be encouraged as much as possible.

IV. Cyclical mating scheme

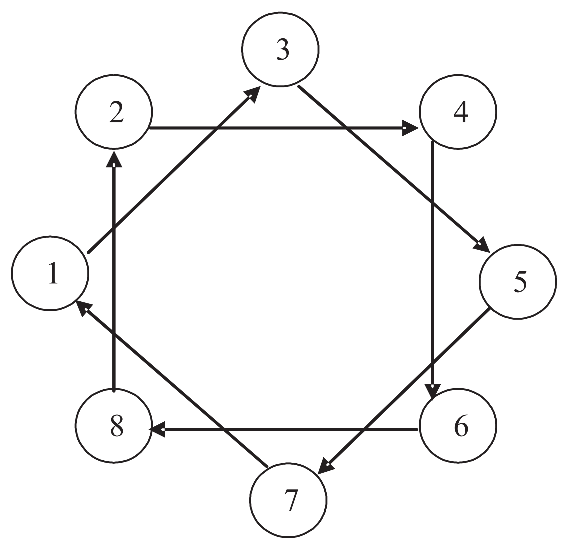
Each group could consist of 400 fish (300 females and 100 males).

Each generation females remain in the group they were bred, whereas males go to another group, following the scheme outlined below.

Each generation select the heaviest males and females as replacements.



Generations 1, 3, 5, ...



2, 4, 6, ...

GENETIC CONSIDERATIONS ABOUT EFFECTIVE DISSEMINATION OF JAYANTI ROHU

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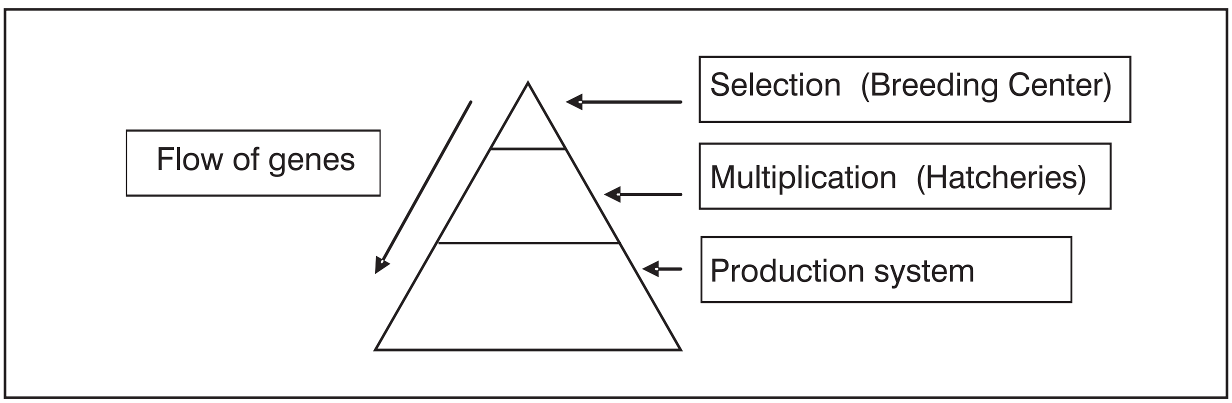
INTRODUCTION

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

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

Figure 1 Flow of genes from the breeding centre to the production system



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

Unfortunately, experience shows that when a successful strain and market for such a strain develop, malpractice often proliferates, facilitated by the very high reproductive rate of fishes, and stock quality deteriorates as a consequence of inbreeding and small population size. There is no simple way out of this, except through the creation of a formal structure, which is, not only technically sound, but that also regulates the process and enables the implementation of quality assurance practices. In the section entitled "Multiplication of Jayanti Rohu in India" (Jiji's) possible formal structures are outlined and discussed. In this section we outline the genetic considerations that should be made to ensure the delivery of high quality seed to farmers, and we formulate recommendations to this effect.

BROOD STOCK MANAGEMENT IN HATCHERIES:

General situation

For many cultured fish species hatcheries have been in operation without the existence of a corresponding genetic improvement program. The bad management of brood stock from a genetic viewpoint has led to the frequently encountered scenario of low and deteriorating performance in hatcheries. This deterioration may be attributed to the combined effect of selection in the wrong direction and to inbreeding (Eknath, 1991). Efforts have been made to explain the genetic basis of the deterioration of stock performance, and to prescribe methods to avoid it. However, when a genetically improved strain such as the Jayanti Rohu is available, the role of hatcheries should not be the "management" of the stock, but rather the rapid multiplication of the latest (most improved) generation of the strain. Here we outline what we consider would be the ideal method of disseminating Jayanti Rohu, and we also provide guidelines for brood stock management in case this latter option was inevitable.

Ideal brood stock management policy for hatcheries

Jayanti Rohu is a strain of demonstrated superior performance relative to other Rohu populations currently used by farmers, and it is undergoing a continuous program of genetic improvement. From the point of view of production of high quality seed, the ideal situation is that hatcheries regularly receive brood stock from the breeding centre at Committee on Inland Fisheries of Africa (CIFA), produce seed from it, and replace it when its reproductive efficiency declines or ceases. In this way, hatcheries would be multiplying and distributing to farmers seed from the latest generation of the nucleus in the breeding centre, with the greatest number of generations of selection behind it. They would not be breeding with the purpose of generating their own replacement brood stock.

The required rate of replacement of brood stock would depend on the hatcheries' individual needs, and it would be related to the wear and tear of brood stock and the anticipated fry output. Because in this scheme hatcheries do not produce their own replacement brood stock, considerations about numbers are of a different nature than when they do. There are, nevertheless, some simple guidelines that should be followed.

Firstly, the number of brood stock in the hatchery at any particular time will have to be consistent with the anticipated output of larvae or fry. This can be easily calculated from the reproductive rate for the hatchery in question. Secondly, steps should be taken to ensure that in the hatchery close relatives are not mated. This can be achieved by supplying, from the breeding centre, brood stock in two groups, say A and B, with the condition that group A is progeny of a different set of parents from group B. If we further impose the condition that in the hatchery males from group A can only be mated with females from group B, and *vice versa*, we eliminate any chance of mating individuals that are full sibs or half sibs. Of course, brood stock could be supplied in more than two groups if that were necessary for some reason.

The brood stock supplied to the hatcheries by the breeding centre would typically consist of individuals that are surplus to the genetic improvement program, individuals resulting from special matings (in addition to those conducted in the context of the genetic improvement program) of selected parents, or redundant parents (i.e. already used in the nucleus but no longer required because a new generation is, or will soon be, available). The use of redundant parents by the hatcheries could be very valuable in rapidly disseminating the genes of the best Jayanti Rohu individuals, thus reducing the genetic lag between the nucleus and the production sector.

A change in the perception that hatcheries have to breed their own replacements would benefit the industry as a whole. The achievement of such a change will require education of hatchery managers and the implementation of procedures of certification of hatcheries that join the scheme and are prepared to follow the necessary protocols. Note that this is the approach that was followed by the GIFT Foundation.

BROOD STOCK MANAGEMENT GUIDELINES WHEN REPLACEMENTS ARE BRED WITHIN THE HATCHERY

General

If Jayanti Rohu were made available to hatcheries with no conditions or restrictions on the use of the stock, their multiplication through the reproduction of a limited number of parents of undetermined relatedness to each other would inevitably result in inbreeding and impaired performance. This would have at least two undesirable consequences. Firstly, farmers would not be able to benefit from the genetic gain achieved in the nucleus, as this would have been eroded by inbreeding depression by the time they received Jayanti fry. Secondly, the poor performance experienced by farmers would give Jayanti Rohu a bad reputation, making its dissemination to other farmers more difficult. Given the resources and effort that have been put into the development of Jayanti Rohu, this would be a most unfortunate turn of events. Hence, the highly formalized scheme of multiplication by continuous stock replacement advocated and described in the earlier paragraphs of this section, and the reservations expressed about the notion of hatcheries producing their own replacement stock.

Inbreeding

Inbreeding is the mating together of individuals that are related to each other through having one or more ancestors in common. The offspring of such a mating are inbred to a degree dependent on the closeness of the relationship between their parents. It is the relationship between the parents that makes the offspring inbred. Either or both of the parents may be inbred themselves, but if they are not related to each other the offspring are not inbred. The primary consequence of inbreeding is to reduce the number of individuals that is heterozygous for any one gene pair, and to increase the number that is homozygous. The reduction in the number of heterozygotes and increase in the number of homozygotes can be worked out mathematically and provides a measure of the degree of inbreeding, known as the *coefficient of inbreeding*. The coefficient of inbreeding ranges from 0 percent at the start, to 100 percent when inbreeding is complete.

There are two practical consequences of inbreeding, both of which result from the reduction of heterozygotes and increase of homozygotes. The more obvious of these is the *inbreeding depression*. The animals become generally less healthy and more susceptible to disease, and their reproductive capacity is reduced due to lower reproductive efficiency and survival. This effect of inbreeding follows from the fact that most deleterious genes are recessive. In a non-inbred strain these genes are present mainly in heterozygotes where, being recessive, they do not show in the phenotype. As inbreeding proceeds, however, they appear more and more often in homozygotes where they exert their full deleterious effect on the phenotype. The second practical consequence of inbreeding is to change the amount of genetic variability among the animals. When inbreeding results from a relatively small population size, rather than from deliberate mating of relatives in a large population, the genetic variation becomes smaller, thus reducing the scope for genetic gain from selection.

Avoiding inbreeding in the hatchery: guidelines.

In this section, guidelines aimed at the maintenance of brood stock quality are provided, and a number of practical suggestions are made.

Effective population size

The effective population size is one of the most important concepts in the management of a population. It depends upon several factors such as total number of breeding individuals, sex ratio, mating system and variance of family size. In a random mating population N_e is calculated as:

$$N_e = 4\ N_f\ N_m\ /\ (N_f + N_m)$$

where, N_f and N_m are the number of female and male brood stock, respectively.

The effective population size is inversely related to the rate of inbreeding per generation (F):

$$\triangle F = 1/2Ne$$

We may also write:

$$\triangle F = 1/(8N_f) + 1/(8N_m)$$

The above equations have a number of important practical consequences. Firstly, the effective population size is not the same as the census size. For instance, two populations, one consisting of 5 males and 15 females, and another one consisting of 10 males and 10 females, have the same census size, but the effective population sizes are 15 and 20, respectively. Secondly, and following from the calculations just made, for a given census size, the effective population size is maximized when the number of females and males used is the same. Thirdly, if we set an upper limit to the increase of inbreeding per generation, say at 1.0 percent, then we can calculate the effective population size that would be required (i.e. 50). This effective population size could be achieved by mating 25 females with 25 males, assuming that they all leave offspring, and that offspring from all pairs contribute to the next generation. Of course, it could also be achieved in other ways.

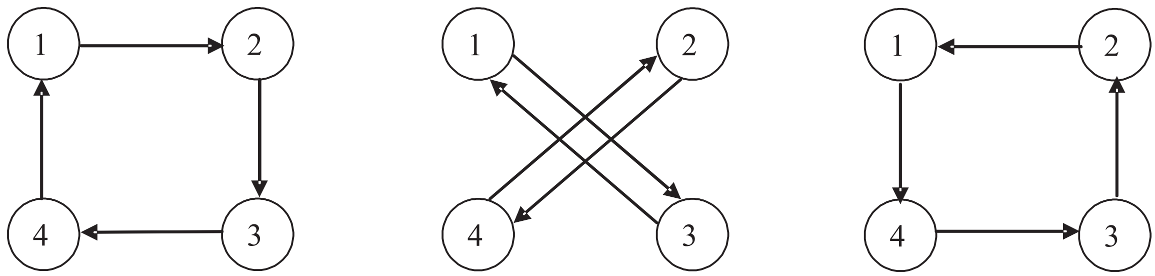
It should be realized that in a closed population of finite size, inbreeding will inevitably occur. The fact that the smaller the N_e the greater rate at which inbreeding will increase has to be kept in mind. If brood stock replacements are produced in the hatchery, the aim of the hatchery manager should be to reduce the rate of inbreeding, by increasing the effective population size. Both private and public hatchery managers will require sound advice and monitoring on this matter, as generally they have limited knowledge about genetic principles and corresponding proper brood stock management. Often, private hatcheries have limited space for brood fish and they are understandably profit oriented. Conflicts can emerge between short-term profit gains and considerations about inbreeding. Preferably, hatcheries undertaking the maintenance of their own brood stock should have a separate unit for that purpose, apart from that producing fish seed for sale.

Practical considerations

The following is a list of practical matters to be attended to by hatcheries engaging in the production of their own brood stock replacements. Note, however, that this is no substitute for person to person discussions with hatchery managers, and for on-going monitoring of the operations.

- Increase the effective population size, as this reduces the rate inbreeding. There is no fixed or ideal number of brood stock that can be universally recommended, but a minimum of 50 pairs in each reproduction cycle is advisable. Repeated use of same brood stock in a way that could result in the mating or parents to their own progeny should be avoided.
- For a given census size, maintaining a ratio of one male to one female among the brood stock will result in the lowest rate of inbreeding.
- Instead of mass breeding, stripping of fish can be adopted, as this will allow greater control of reproduction and of the contribution of parents to the next generation. Also, it may enable the avoidance of matings among close relatives.
- Hatchery managers should have detailed knowledge of their brood stock. For instance, they should maintain records on the location (e.g. pond, tank) where each stock is. Keeping year or age classes separate is useful.
- Marking in some way or fin clipping can be carried out for identification of different groups of brood stock. Even in cases in which the fish cannot be individually identified, keeping different groups will enable the organization of mating in ways that delay the onset of inbreeding, and that result in a more uniform rate of inbreeding in the population than random breeding. Figure 2 shows how mating could be organized with four such groups. The groups could be year classes or could be nominated by the breeding centre on the basis of parentage. The arrows indicate the transfer of males. The principle is that male progeny are mated with females of a different group from the one in which they were born. The transfer follows the pattern indicated in the diagram. Males are transferred in the directions indicated by the arrows, whereas females stay in the group they were born. The pattern of transfer varies with the generation number. This is a relatively simple mating system, and it can result in considerably less inbreeding than random mating (Nomura and Yonezawa, 1996). Of course, the scheme can work with a greater number of mating groups, and the greater the number of groups, the lower the rate of inbreeding.

Figure 2 Cyclic mating scheme to avoid inbreeding



Generations: 1, 4, 7, ... 2, 5, 8, ... 3, 6, 9, ...

- Periodical (and preferably frequent) introductions of brood stock from improved stock or from hatcheries with a reputation of having good performance should be undertaken. Crossing with the hatchery's stock will undo any inbreeding and introduce genetic variation. However, the identity of the introduced stock should not be lost, and it should be stocked separately, in readiness for further matings.
- The use of cryopreserved milt can increase the effective population size, and save rearing space that would have to be assigned to male brood stock. Milt should be from improved stock or from males from another hatchery with a reputation of good performance. The use of cryopreserved milt would not only reduce the requirements for rearing space for the males, but would also facilitate transport from one place to another.

Concluding remarks

In order to capitalize on the effort made in the development of an improved strain, its dissemination to farmers must be effective. To this end, the relative sizes of the population sectors involved in selection, multiplication and production should be examined and made consistent with an effective transfer of genetic gain to the production sector.

We advocate the implementation of a policy of continuous replacement of brood stock in the hatcheries, from regular supplies made by the breeding centre. This will most likely require a process of certification of hatcheries that agree to comply with an established protocol of brood stock replacement and management. The certification will ensure the quality of the brood stock used in the hatchery and of the larvae or fingerlings produced. This is the preferred option to be considered in the multiplication and dissemination of Jayanti Rohu.

We discourage the notion of hatcheries engaging in the production of brood stock. Experience shows that this is likely to result in inbreeding and impaired performance, and lead to damage to Jayanti Rohu's reputation. We recognize, nevertheless, that the practice of producing their own brood stock is entrenched in the industry, and for that reason we provide guidelines on management to avoid inbreeding and a deterioration of performance.

A lesson to be learned from other (terrestrial) species is that the processes of multiplication and dissemination occur in a more systematic and effective manner when special resources are assigned to the task. In the particular case of Jayanti Rohu, it is our perception that at least one person (and preferably two) with background knowledge of animal breeding and of the carp industry in India should be given the responsibility of implementation and of continued supervision of the hatcheries involved. Of course, the person(s) involved should be provided with the necessary operational resources to carry out the task. Relying on existing staff with numerous other responsibilities will reduce the chances of success. The feedback provided by the person(s) involved to the Breeding centre on matters related to the genetic improvement program will be an extremely valuable by-product of the activity.

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APPENDIX D

NACA AS A TEMPLATE FOR NACAF[12]

NACA history

NACA was identified by the 1975 FAO Regional Workshop on Aquaculture Planning in Asia, and adopted by the 1976 FAO Technical Conference on Aquaculture in Kyoto.

The need of regional aquaculture centers was recognized on both occasions as essential to the coordination of cooperative research, training and information exchange in a collective effort to promote aquaculture development on a regional basis, especially with emphasis on sharing available resources in accordance with the concept of Technical Cooperation among Developing Countries (TCDC).

Despite diverse development emphasis on aquaculture systems in the Asia and the Pacific Region, there was a keen interest to transfer known aquaculture technologies among the countries making it possible for effective cooperation in the transfer of technical know-how under the project's mandate. Accelerated collective development was made possible through cooperative research, training and information exchange activities.

The project was signed on 7 June 1979 by 11 participating governments, namely, Bangladesh, China, Hong Kong, India, Indonesia, Malaysia, Nepal, the Philippines, Singapore, Sri Lanka and Thailand. Activity implementation started in August 1980 upon the appointment of the Project Coordinator, with the project office located at the National Inland Fisheries Institute, Bangkok.

Vision

NACA is an intergovernmental organization that promotes rural development through sustainable aquaculture. NACA seeks to improve rural income, increase food production and foreign exchange earnings and to diversify farm production. The ultimate beneficiaries of NACA activities are farmers and rural communities. The core activities of NACA are:

- capacity building through education and training;
- collaborative research and development through networking among centers and people;
- development of information and communication networks;
- policy guidelines and support to policies and institutional capacities; and
- aquatic animal health and disease management.

[12] *Source*: http://www.enaca.org/modules/wfchannel/

Structure

NACA policy is determined by the Governing Council composed of high officials representing in the member governments. The Governing Council regularly meets once a year and formulates NACA's 5-Year Regional Work Programme. FAO is a non-voting member. The NACA Agreement provides for other international and government assistance agencies to be non-voting members, by invitation.

Members

Current member governments are Australia, Bangladesh, Cambodia, China, Hong Kong SAR, India, Iran I.R., Korea (DPR), Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, Viet Nam. Other participating (non-member) governments include Indonesia, Rep. of Korea, Lao PDR and Singapore.

Collaborating agencies

NACA conducts development assistance projects throughout the region in partnership with governments, donor foundations, development agencies, universities and a range of non-government organizations and farmers. NACA supports institutional strengthening, technical exchange and the development of policies for sustainable aquaculture and aquatic resource management.

NACA's partners include organizations such as FAO, United Nations Development Programme (UNDP), the Asian Development Bank, World Bank, World Organization for Animal Health (OIE), the Mekong River Commission, International centre for living Aquatic Resources Management (ICLARM), South East Asia Fisheries Development Commision (SEAFDEC), Asia Pacific Economic Conference (APEC), Association of South East Asian Nations (ASEAN), European Union (EU), Danish International development Agency (DANIDA), Department for International Development (DFID), Australian Centre for International Agricultural Research (ACIAR), AusAID, Danish Cooperation for Environment and Development (DANCED), International Development Research Centre (IDRC), Institut Francais de recherché pour l'exploitation de la mer (IFREMER), Norwegian Agency for Development Cooperation (NORAD), the Asian Institute of Technology, World Wide Fund for Nature, MacArthur Foundation and the Rockefeller Brothers Fund.

OPERATION OF NACA

I. Introduction

NACA is an intergovernmental organization[(1)]. Cooperation among members underpins its operation. Such cooperation facilitates the exchange of known technology, exchange of scientific findings, dissemination of new knowledge and information, and exchange of expertise. Networking makes the above activities economical and very effective: There is no duplication because of lack of communications, participating institutions and experts build on and add value to each others' work, they can work together to solve a common problem, and the strengths of each and every institution are brought to bear on addressing common issues. Just as important, such cooperative work will also strengthen the capacities of every participant, and therefore of the whole network. The new information and communications technology (ICT) greatly facilitates networking although it may not necessarily enhance cooperation.

II. Lessons from the NACA experience

1. Technical cooperation works

Sharing resources and responsibilities among institutions (and countries) through networking is probably the only practical and cost-effective means available for solving the diverse problems faced by aquaculture due to the sheer diversity of species, farming systems, environments, and varying levels of development among countries. The networking (and sharing) approach is also in line with governments' objectives of regional self-reliance through technical cooperation.

Cooperation becomes more compelling in the face of limited resources of governments and donors, and the need to best utilize internal resources and external support. The complex and many challenges faced in the development of aquaculture, a relatively new economic activity, also argue for a collaborative approach to make efficient use of resources to solve problems. Adding a very important dimension to cooperation, the NACA members have committed to the principle that the stronger members shall assist the others.

2. Ownership and continuity of initiatives

Programs and projects are developed so that they address the priority issues and needs expressed by members (governments). These expressed needs and priorities are translated and formulated into a regional action plan (by the Technical Advisory Committee of NACA), which is adopted into the regional Work Program – a rolling Five-Year Plan - by the Governing Council. Three attributes of the NACA work program emerge from this arrangement; the program is: (i) owned by members; (ii) a product of consultations among the various stakeholders, and (iii) implemented by the members themselves in a cooperative and coordinated way that builds on the capacities in the countries and complements those of the regional institutions.

These attributes make two important conditions happen: (i) governments commit resources to implement the programs, and (ii) governments and interested institutions in the respective countries take up the results in their policy and programs. As such activities are taken up in NACA's work program the various initiatives are assured of continuity, rather then being terminated when the project ends.

Another significant point is that the regional program is based on common needs and priorities of the members, not on the overriding interests of one or two.

3. Strategy for capacity building of the Network

When NACA evolved from a UNDP/FAO Project to an independent inter-governmental body (in 1990 after 9 years as a regional project), it adopted a major change in operational strategy. It had to: (i) become self-sustaining in order to finance core activities (such as technical advice, information exchange, and overall network activities coordination and secretariat administration), (ii) generate revenues by provision of services against payments, (iii) develop programs and projects for collaborative assistance of donors and development agencies, and (iv) enter into partnerships with other institutions and work with them on areas of common interests.

These made it possible for NACA to continue as a focal point for the implementation of multilaterally and bilaterally funded regional and national projects.

Partnership and collaboration becomes a mutually beneficial arrangement if the independence of the Organization is maintained. In practical terms, its programs should be developed and owned by the members and not imposed or influenced by external agencies; it has the basic organizational capacity and resources to operate the programs; and the interest of donors should match the priorities of the organization, not the other way around.

4. Demonstrating results

The overall strategy in project implementation emphasized four priority thrusts: (i) increase aquaculture production through effective transfer of proven technologies in the region; (ii) train senior personnel in the planning and management of aquaculture development and production projects; (iii) help justify government financial support to national aquaculture projects; and (iv) take on only relevant adaptive research that facilitates increasing production, leaving basic research though complementary activities from academic institutions.

Priority was thus given to producing early, visible and measurable results for increasing aquaculture production in the region. This was aimed to assert the economic and social importance of aquaculture for the attention of development policy planners in governments. This was achieved by effective transfer of established viable, commercial technologies and techniques through applied and adaptive research in both host and recipient countries. The trials of established aquaculture production systems adapted them to local conditions. Through the cooperation among the centers, technical and managerial details of established aquaculture production practices were systematically transferred by way of training courses, workshops and seminars, as well as specialized technical assistance (i.e. expert exchange) and via information dissemination.

5. Providing the science to traditional production practices

In Asia, established aquaculture production technologies have a long tradition. They evolved through traditional trial-and-error practices. Research was then disciplinary or very specific-problem focused rather than systems oriented. NACA thus emphasized research that would promote scientific understanding of vital interrelationships of salient dependent and independent variables for the improvement of production systems of importance to the region. As an example, the age-old highly productive integrated fish farming systems in China – evolved through many centuries into an art by Chinese farmers – were studied and given scientific basis. As such, the technology was provided scientific explanation and therefore transferred more easily throughout the region through workshops, training, information and extension. It then also became susceptible to further scientific improvement.

III. The NACA Work Program: How it is developed and its characteristics

The present 5-year work program is for the period 2001-2005. It is the third since NACA became independent in 1990. The work program is actually a rolling plan, in that activities are "rolled into" the next program rather than having finite life spans during the 5-year period. NACA's Secretariat in Bangkok coordinates the implementation and monitoring of the work program. In program formulation the Secretariat provides the information and resources needed by the Technical Advisory Committee to review the status of the program.

The Technical Advisory Committee (TAC) is composed of national (member country) technical experts and joined by representatives of industry, academic institutions, farmer groups and NGOs. It meets every 2 years to (i) review the progress of the implementation of the programme, (ii) develop a 2.5-year plan of work to implement the work program, and (iii) recommend future activities to the Governing Council. TAC meetings are conducted in a workshop mode, rather than in a conference mode. The basic government membership imbues ownership of the technical program, while the co-opting of other participants representing the primary stakeholders of aquaculture development ensures that the technical program benefits from excellent intellectual inputs and informed by a broad range of stakeholders' views.

The Governing Council decides on policy matters. It formulates the work program based on the recommendations of the TAC. Participation in the Governing Council includes member governments, associate members, FAO, and representatives of donor agencies and collaborating institutions. In practical terms, this wide range of participation translates into a broad ownership of the program.

Elements of the work programme

Over the years, there have been changes in regional priorities and therefore the elements of the work program have also been changing to reflect and address these priorities. The present work program consists of six major elements:

- Support to Regional Aquatic Resources Management or STREAM
- Capacity Building through educational and training programmes
- Effective R & D by collaborative networking among centers
- Information and communication
- Policy guidelines and support to policies and institutional capacities

- Aquatic animal health management

Added during the current program period were Trade and Market Access and Farmer and Industry Affairs.

Characteristics of the work programme

1. **Current emphasis:** The work programme emphasizes rural development, focusing on the social and environmental objectives of reducing poverty, ensuring food security, enhancing livelihoods, managing aquatic resources, promoting a healthful environment and healthy aquatic animals, and improving management and technical skills. The Governing Council revised in 2000 the traditional emphasis from "aquaculture development" to "aquaculture for rural development."
2. **Pillars:** The program is based on building capacities through better education and training and improving support to policies and institutions, facilitating effective research and development by collaborative networking among centers and individuals, and facilitating the sharing of information.
3. **Working principle:** The program gives relevance to the different efforts to assist governments develop and implement their aquaculture programs by reflecting their viewpoints and needs.
4. **Guideline for cooperation:** Its outlook on regional cooperation is to provide a forum, and facilitate the process, for stakeholders to act as partners with governments, add value to each other's efforts (rather than duplicating them), and collectively own the decisions and policies, therefore drawing stronger commitments from every partner.

Conclusions

From the above discussions, we can draw three major conclusions on the benefits from a regional networking arrangement of governments (or institutions).

1. From the point of view of results, a broad-based collaboration on specific programs involving numerous institutions can multiply benefits to the institutions themselves, to governments and to the people in the aquaculture industry. Cooperation in areas of mutual interests – through specific programmes or projects – can effectively muster resources, expertise and institutional support to implement regional projects, promoting synergy, avoiding duplication of activities, and expanding the range of beneficiaries. NACA has generated support for the implementation of major regional and national activities from bilateral, multilateral and investment agencies.
2. From the capacity building perspective, training of national personnel and upgrading of facilities have created a multiplier effect for various assistance programmes. In other words, the improvements that NACA brought about on regional and national capacities (that include trained people, more efficient operating and management systems, and upgraded facilities) have attracted and made it easier for donor assistance programs to be effectively implemented. The multiplier effects include (a) wider dissemination of results, (b) assurance of follow-up activities within governments thus ensuring continuity of project-initiated activities in the NACA program of work, and (c) utilization of strengthened national institutions by various assistance programs.

3. Cooperation and commitment are the basic forces that move the organization, but they must also be expressed in practical terms by the participants by contributing resources to the management and operation of the organization.

Footnote

1: Current member governments are Australia, Bangladesh, Cambodia, China, Hong Kong SAR, India, I.R. Iran, Korea (DPR), Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, Viet Nam. Other participating (non-member) governments include Indonesia, Rep. of Korea, Lao PDR and Singapore. The South Pacific Nations are, collectively, Associate Members through the Secretariat of the Pacific Community.

APPENDIX E

PROJECT CONCEPT: IMPROVED TILAPIA STRAINS FOR AQUACULTURE IN AFRICA

Public-Private Partnership:

Food and Agriculture Organization of the United Nations, WorldFish Center, Public and Private Sector Partners[1]

Objectives:

1. Make available improved strains of tilapia and catfish for African fish farmers through the establishment of an African Regional Fish Breeding Programme.
2. Develop and implement protocols for monitoring, control and environmental risk assessment for aquaculture, in particular the use of improved strains.

Time Frame: 5 Years

Budget: $3.5 million

Aquaculture is growing and diversifying in Africa. In addition to innumerable family fish farms, there is now a growing number of small-, medium- and larger-scale commercially orientated investments. While most family fishponds receive few, if any purchased inputs nor benefit from intensive management practices, commercial farmers of all scales use as close to state-of-the-art technology as possible; including complete feeds, high density stocking, aeration and other modern technologies. Many of these farms are competing in regional and international markets where cost of production is a major concern.

The establishment and expansion of commercial fish farming in sub-Saharan Africa has created new opportunities to realize major contributions to food security and economic growth that have long been anticipated from the aquaculture sector. A key element in the productivity and profitability of these farms, as with any animal or agricultural enterprise, is the use of improved strains for culture.

Deterioration of genetic quality in cultured fish populations has been well-documented and accounts for productivity losses of about 40 percent compared to the wild stock from which they came. Poor hatchery management, especially inbreeding, out-crossing (to wild fish that enter the system) and inadvertent selection are the main causes. Breeds developed outside of Africa have, on the other hand, been substantially improved through selective breeding and are widely used on Asian and Latin American fish farms.

In February 2006, a regional Workshop on Genetic Management of Aquaculture Stocks in Sub-Saharan African brought together representatives of the small, medium and large-scale commercial aquaculture sub-sectors to discuss directly with fish breeders, population

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[13] Potential public sector partners include: Kajjansi, Uganda; Sagana, Kenya; Domasi, Malawi; Mwekera, Zambia; Akosombo, Ghana; Foumban, Cameroon; Pt. Harcourt, Nigeria; among others.

geneticists and environmentalists the possibilities for, and constraints to, the development and use of improved fish strains. A key output is a proposal to establish an African Regional Fish Breeding Programme for the establishment of which this project concept has been elaborated.

Project description

While private sector fish hatcheries are quite active in several countries, at the present level of development, individual countries can hardly justify investments in quality-controlled fish breeding facilities. On the other hand, a large number of aquaculture research facilities exist across the continent, most of which have been envisioned at least partly as fish breeding and/or brood stock management stations, pending the growth of demand and available funding.

We propose to establish sub-regional networking and genetics information centers in at least three countries where aquaculture is experiencing significant growth (countries to be designated based on region, logistics and infrastructure availability). Housed at these centers would be experienced fish breeders who would implement selective breeding programs for the main indigenous fish species groups grown in Africa, namely the tilapias and clariid catfishes.

Based on the structural relationships between breeding centers (Figure 1), hatcheries and fish farms that have evolved and function effectively on other continents, the breeding centers, or nuclei, would provide improved brood stock to hatcheries and their subsidiaries within a pre-established distribution area. These hatcheries and subsidiary satellite hatcheries or nurseries where applicable, would, in turn, provide improved seed to growers.

The breeding centers would also provide to private sector fish hatcheries technical guidance on the use and management of improved fish strains in addition to supplying (at cost?) high quality brood stock. These hatcheries would then reproduce the improved brood stock from the breeding centers to supply grow-out farms.

To ensure that maximum economic and food security impacts from the breeding programme, a seed certification process would be put in place whereby the capacity of local hatcheries to properly manage and protect improved strains would be assessed and documented. As improved strains will not help farmers who do not use suitable feeds and other advanced management techniques, grow-out farm certification would also be done in order to assure that best management practices are being followed. Only certified hatcheries could buy and/or sell improved fingerlings and only to certified producers.

In conjunction with the development of improved lines of fish, the provision of technical services in fish genetic management and the certification of hatcheries and grow-out farms, necessary research would be conducted to develop guidelines for environmental risk assessment for the use of improved strains of fish in aquaculture. The main elements of this programme would include:

- Tracking and measuring rates of genetic introgression (probably based on the fixation index, Fst).
- Monitoring of fish catch trends in watersheds where improved strains are being cultured (using catch per unit of effort, CPUE).

- Identifying genetic markers for improved strains so as to track their dissemination for purposes of control.
- Sterilization techniques that could be used to eliminate most environmental risks arising from the spread of tilapia aquaculture should be seriously considered.

Project outputs:

1. Improved strains of fish for aquaculture. If rates of gain realised elsewhere are replicable in Africa, this should be on the order of 50% over 5 years.
2. Best management practices (BMP) for reproduction, management and grow-out of improved fish strains. Use of BMP could easily double current yields.
3. A seed certification program. This would protect both hatcheries and grow-out by assuring quality.
4. Guidelines for environmental impact assessment (EIA).
5. Improved human resource capacity in genetics management in both private and public sectors.

Long-term sustainability

As part of the initiative set in motion in Accra, two other parallel activities are being undertaken by the FAO and WorldFish in close partnerships with the expanding number of commercial aquaculture producers in Africa:

- Development of a producers' union, network or association evolving out of existing information networks (e.g., Aqua-Africa, International Network of Genetics in Aquaculture, etc.). This group would serve as the main lobbying group and information dissemination structure for the private sector, and would evolve into:
- The Network of Aquaculture Centres of Africa (NACAf) along the lines of the Network of Aquaculture Centres in Asia. This centralized technical support body would be comprised of experts in various aspects of aquaculture, mostly derived from existing national programs in the region. Ultimately, the various national centers from which this expertise would be drawn, would narrow their mandate from one of comprehensive national research and development institute, to a component center of the NACAf, focussing on one or a few specific aspects of the larger regional agenda.

It is this NACAf that would ultimately take control of the African Regional Fish Breeding Programme as part of its agenda, thus providing the necessary platform for continued public-sector support to further aquaculture expansion. Such a system would rationalize the current diffuse supply of aquaculture technological backstopping, taking advantage of the relative strengths of existing national programmes. It would also put in place a structure which could be easily monitored and through which international donor contributions could be effectively channelled.

If neither national nor international financial support is forthcoming at the completion of the initial stages of the African Regional Fish Breeding Programme, and the NACAf is not functional, the breeding centre(s) would be attractive business investments for either international, regional or national aquaculture entrepreneurs.

APPENDIX F

PARTICIPANTS' FEEDBACK

A questionnaire was distributed to all participants to seek feedback on the producer-centerd workshop as well as suggestions as to how best to organize future activities. Ten questionnaires were returned to the organizers with the following conclusions:

- All respondents found the workshop useful;
- All respondents felt the regional nature of the workshop was advantageous;
- 50 percent felt similar workshops should be held every year while 20 percent indicated they should be held twice a year;
- 70 percent would be willing to lobby decision-makers at their homes to implement decisions made at the workshop;
- 50 percent would be able to pay some of the costs relating to their participation, but none were able to pay the full fare;
- 70 percent were willing to distribute workshop materials and other related technical or training documentation to colleagues at home;
- 70 percent appreciated receiving documentation on CD - ROM.

Among those aspects of the workshop that participants felt to be the most useful were:

- the attempt to bridge the knowledge gap between producers and the scientific community and policy-makers;
- the opportunity for farmers to contact each other;
- practical exchange of views on aquaculture;
- the opportunity for participants to freely express their views;
- the structure that provided exposure to modern approaches to aquaculture development as well as the challenges to this development;
- the presentation of easy to follow scientific explanations.

Participants proposed that future producer-focused workshops might target the following subjects:

1. fish feeds and feeding;
2. causes of mortality in juvenile cultured fishes;
3. ways of improving aquaculture production (yield);
4. regional training tools and mechanisms;
5. policy-maker/producer dialogue on promotion of aquaculture;
6. aquaculture start-up requirements and procedures;
7. best management practices.

APPENDIX G

NAIROBI DECLARATION

Nairobi declaration

CONSERVATION OF AQUATIC BIODIVERSITY AND USE OF GENETICALLY IMPROVED AND ALIEN SPECIES FOR AQUACULTURE IN AFRICA NAIROBI, KENYA 20 -23 FEBRUARY 2002

An *Expert Consultation on Biosafety and Environmental Impact of Genetic Enhancement and Introduction of Improved Tilapia strains/Alien species in Africa*, was convened in Nairobi, Kenya from 20 to 23 February 2002 under the sponsorship of ICLARM. The WorldFish Center, the Technical Center for Agricultural and Rural Cooperation (CTA), the Food and Agriculture Organization of the United Nations (FAO), the World Conservation Union (IUCN), the United Nations Environment

Programme (UNEP) and the Convention on Biological Diversity (CBD), to discuss and develop guidelines that will foster the development of aquaculture while maintaining biodiversity. The meeting was attended by aquaculturists, geneticists and conservation specialists from Africa and from international organizations. Following four days of discussions the participants endorsed the Nairobi Declaration on Conservation of Aquatic Biodiversity and use of Genetically Improved and Alien Species for Aquaculture in Africa.

Background

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

At present fish production from aquaculture in Africa is low. However as population increases, together with demand for fish, the aquaculture sector is projected to grow. For this to happen, a wide range of constraints need to be addressed and a greater range of management practices considered. Pond and broodstock management will need to be improved, a wider range of feeds developed, and market access improved. In addition, there is considerable potential for improving performance of the fish species and strains used. At present many of the fish used in aquaculture in Africa are derived from undomesticated stocks. This contrasts with crops, livestock and poultry where large increases in production have been achieved through application of breeding programs and other genetic improvement procedures. However, while improved strains and introduced species have potential to increase production there is clear risk of escape into the wild, and possible negative impacts on biodiversity. If the full potential for sustainable aquaculture in Africa is to be realised these concerns need to be addressed.

RECOMMENDATIONS

1. Quality seed

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.

2. Genetics in broodstock management

Since genetic resources in cultured populations can be degraded as a result of captive breeding, genetic aspects of broodstock management need to be a basic element within all aquaculture and stock enhancement programs.

3. Responsible introductions

Introductions of fish, including genetically improved strains and alien species, may have a role in the development of aquaculture. Any movement of fish between natural ecological boundaries (e.g. watersheds) may involve risk to biodiversity and there is need for refinement and wider application of protocols, risk assessment methods, and monitoring programs for introductions of fish, including genetically improved strains and alien species. States have an 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.

4. Conserving wild stocks

Unique wild stocks of important tilapia species still exist in many parts of Africa. Priority areas should be identified and managed as conservation areas in which introductions of alien species and genetically improved strains should be prevented.

5. Transboundary problems in fish transfer

The majority of issues and problems associated with movement of fish and the use of genetically improved strains are common to most African countries. Countries are encouraged to: (a) look beyond borders for examples of workable policies and legislation, adopt them where appropriate to fill national policy gaps, and harmonize them where necessary; and (b) use existing regional bodies or form new bodies to assist in coordinating management activities taking into account ecological realities, in particular trans-boundary watersheds.

6. Strengthening access to information

Baseline information on fish genetic diversity, environmental integrity and aquaculture practices exists, but it is neither comprehensive nor easily accessible. The existing mechanisms for collection and dissemination of information need to be strengthened.

7. Controlling pathogen movement

Internationally accepted codes and protocols for reducing the risk of trans-boundary movement of pathogens through movement of fish including alien species do exist, but they do not address any specific needs regarding genetically improved species. States and other relevant bodies should evaluate the existing codes and protocols for reducing the risk of trans-boundary movement of pathogens through movement of fish including alien species and genetically improved strains, and adapt them for African conditions. 1 the term pathogen used here includes parasites

8. Raising awareness of risks of fish introduction

Policy makers, 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 altered species, and this should be high on national agenda.

9. Engaging stakeholders

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. In addition, governments should establish advisory groups with links to independent and scientifically competent expert bodies such as FAO, IUCN, and ICLARM of the World Fish Center.

10. Liability for adverse environmental impacts

Although economic benefits can be derived through the use of alien and/or genetically improved species 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 provision for liability, compliance (e.g. incentives) and restoration within policies and legislation concerning the movement and use of alien and genetically improved fish species in aquaculture.

APPENDIX H

ABUJA DECLARATION: NEPAD FISH FOR ALL SUMMIT

1. *Support* regional cooperation in fisheries and aquaculture through NEPAD, Regional Economic Bodies and Regional Fisheries Management Organizations, including in the management of Transboundary and shared aquatic resources and ecosystems.

2. *Support* national actions to accede to, to ratify, and to implement

   international conventions for the sustainable use and protection of the living aquatic resources and the aquatic environment of the region

3. *Implement* the provisions of the FAO Code of Conduct for Responsible Fisheries, in particular through improved governance of fisheries, ensuring the environmental sustainability of fisheries; examining means to progressively replace "open access" to fisheries resources with "limited access regimes" and introduction of rights based fisheries; taking steps to control fleet and fishing capacity; and ensuring an equitable balance of resources allocation between small-scale and industrial fishers.

4. *Empower* fishing and fish farming communities, civil society and stakeholder organizations to effectively participate in policy-making, planning and implementation processes, with particular reference to the equitable allocation of resources, and the rights of the poor and disadvantaged

5. *Ensure* that fisheries and aquaculture is adequately reflected in the national and regional economic policies, strategies, plans and investment portfolios, including poverty reduction and food security strategies.

6. *Foster* the development of an appropriate investment climate for fisheries and aquaculture, including legal and institutional reform and enforcement where required, improved incentives and access to capital for private investors, and strategic public sector investment;

7. *Direct* particular attention to harnessing the potential and entrepreneurship of small-scale fishers, fish farmers, fish traders and service providers and their associations, including women entrepreneurs who have been leading the development of fish processing and trade in much of the continent.

8. *Foster* small, medium and large-scale aquaculture production in a sustainable and environment-friendly manner compatible with the rational use of land and water resources and evolving market opportunities;

9. *Build* human and institutional capacity at national and regional level with particular emphasis on training institutions, transferring appropriate technologies and knowledge to small producers and ensuring a rational and scientific basis for management decisions and design of programs;

10. *Conserve* and rehabilitate aquatic environments and habitats essential to living aquatic resources and aquatic biodiversity; and take measures to prevent or mitigate adverse impacts of aquaculture on the aquatic and coastal environment and communities;

11. *Promote* trade in artisanal and industrial fish products to respond to regional and global market opportunities for African fish products, including by removal of intra-regional trade barriers, developing common approaches and positions on international trade in fish and fishery products and on harmonizing standards on products traded in the region.

12. *Pursue* these objectives through NEPAD and Regional Economic Communities, in collaboration with international partners in science and development;

13. *Contribute* to the creation of an enabling environment for sustainable fisheries and aquaculture development by facilitating the adaptation of existing regional, national, and local institutions and regulations to the challenges and opportunities'

14. *Call* upon the international community to provide the financial and technical support required to implement sustainable African fisheries and aquaculture through aligned and harmonized partnership arrangements and in pursuance of NEPAD's vision and principles for action.

TR/D/AG388E/1/07.06