Capacity for Developing and Managing Genetically Improved Strains of Tilapia in Africa Including Broodstock Management and Quarantine

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Abstract

Human and institutional capacities for developing and managing genetically improved tilapia in Africa are discussed. Discussions are related particularly to the status of hatcheries, rearing facilities, research and extension services, training in genetic enhancement, and fish transfer in major aquaculture countries in Africa. The leading aquaculture producing countries are Egypt and Nigeria along with nine other countries with some intermediate levels of fish production. The availability of quality fry and fingerlings constitutes a major constraint. Hatcheries constructed to increase fry and fingerlings production are non-functional in almost all countries in Africa, except Egypt. Even if these infrastructures are functional, either the production is low or the production cost is so high that fry produced are not accessible. The lack of government commitment and capacity, low priority for the rural aquaculture and insufficient specialized extension agents are some of the constraints to human capacity development. Research and extension, development of methods, tools for improved farming and promotion of their adoption by farmers may be some of the solutions to enhance tilapia culture.

Introduction

Aquaculture was introduced in Africa more than 50 years ago. However, its contribution to the world production remains anecdotal in spite of the tremendous effort put up by the governments of some countries and the international community. From 1984 to 1997, it contributed 0.4 per cent of the world production, reaching 122 000 t in 1997 (Pedini 2000).

In spite of the low performance of aquaculture, fish represent an important component of the diet of the human population in Africa. Fish represent a minimum of 30 per cent of animal protein consumed in different countries of the region (FAO 1997a). The major aquaculture producers in Sub-Sahara Africa are Kenya, Madagascar, Nigeria, South Africa, Zaire, and Zambia. Although fish is an important part of the overall animal protein consumption, aquaculture has so far played a minimum role. In Zambia, 25 per cent of animal protein is from fish, but only 1.7 per cent of this is from aquaculture (Harrison 1996). Aquaculture provides 15 per cent of the total fish production in Egypt and fish farming accounts for 10 per cent of the animal protein required. The species cultured are mostly catfish, Chinese carps, common carp, mullet and tilapia in polyculture systems (Elghobashy 1997).

With the increasing food insecurity aggravated by rapidly growing human population, periodic environmental and climatic calamities, sometimes combined with civil and economic instabilities, aquaculture has the potential to offset the prevailing food imbalance (FAO 2000a). Furthermore, overexploitation of fish resources and irresponsible use of prohibited fishing gears have led to the depletion of wild fish populations; consequently, a decrease in the total production in Africa. Aquaculture, therefore, represents one solution to this situation. FAO (2000a) estimates that in the year 2030, aquaculture will be the main source of fish in the continent.

Despite the difficulties related to aquaculture development, effort must be made on reaching levels of production that can satisfy the needs of the African human populations. The importance of genetic diversity and, in particular, fish genetic diversity has been highlighted recently in many fora (Pullin and Casal 1996; Abban et al. 2000). This confirms the entry into force of the Convention on Biological Diversity, as related to the important role of genetic resources in providing food and other products to humankind. This paper will essentially cover the aquaculture of tilapia, the main cultured species in major producing countries that can be subdivided into three categories:

(1) The two leading countries, Egypt and Nigeria whose production were 62 000 and 17 000 t, respectively in 1995 (FAO 1997a).
(2) The second group composed of nine countries (Congo Democratic Republic, Cote d'Ivoire, Kenya, Madagascar, South Africa, Sudan, Tanzania, Tongo, and Zambia) of which the leading country is Madagascar. The annualproduction in these countries varied between 1 000 and 5 000 t (FAO 1997a).
(3) The third category constituted all the other African countries.

Infrastructure

The failure of aquaculture in Africa has been attributed to various causes. In Senegal, Diallo (1997) reported that technical, environmental, and socio-economic constraints are some of the causes of failure. The first fish-ponds were built in 1947 in Cameroon and 12 000 family ponds were functional. Yet in 1988, only 3 000 to 5 000 remained functional (Nguenga 1988). The decline in the number was attributed to the lack of skills to manage the fish stock, poor pond construction techniques, budget restrictions, and reduction in donors' aid. Many fish-ponds were dug in Sierra Leone and Kenya, only to be abandoned a few years later. The early activities focused on the transfer of proven technologies through regional programs (FAO 2000b).

Status of Hatcheries

Non-availability of fry and fingerlings in quantity and in quality constitutes a major constraint to the development of aquaculture in Africa. Fingerlings supply has been a chronic problem due to various reasons, including the high cost and poor transportation facilities. Different strategies have been developed in many countries to overcome these constraints, such as the construction of hatcheries at various sophisticated levels. In Egypt, fish farmers have used two types of structures in the production of fry and fingerlings: hatcheries and fingerlings collection stations constructed in various administrative regions of the country. Their production capacity was estimated in 1997 to vary between 50 and 100 million fry per year (FAO 1997b). Fry collection stations are located in Damietta, Kafr - El–Sheikh, Behira, Alexandria and Harbor - Said (FAO 1997b). In addition to these infrastructures, projects such as those in Abbassa and Mariut have very large capacity for the production of fingerlings of tilapia and other species.

Nigeria is the leading fish-producing country in Sub-Saharan Africa, particularly in tilapia production. However, the availability of statistics is not always easy, due to logistics and organizational constraints. Nigeria had 20 fish seed multiplication centers; but only eight were under full operation (FAO 2000b). In spite of the relatively high level of production of tilapia in Nigeria, the operation of hatcheries is confronted with the same difficulties as the other countries.

Madagascar (4 712 t), Tanzania (4 200 t), Zambia (4 081 t), and the Republic of South Africa (3 861 t) have an intermediate level of production (FAO 1997a). Very few production farms have been developed in South Africa. However, tilapia production increased from 40 t in 1991 to 110 t in 2000 (FAO 2002). Small-scale rural aquaculture is more developed than the commercial operations. Although modern hatcheries exist in some countries like Côte d'Ivoire, the costs of fry and fingerlings production, as well as the cost of transportation make seed inaccessible to the majority of fish farmers. Only commercial farmers can afford to purchase seed from these hatcheries.

Small-scale farms produce their own seed. Nonetheless, some hatcheries of specialized state-owned or private organizations continue to be operational despite the low level of production. These hatcheries were established to supply fingerlings to fish farmers, but they have not been able to fulfill their mandate. Côte d'Ivoire reported 19 hatcheries in addition to three other governmental aquaculture facilities. However, five of these are no longer functional (FAO 2000b).

Although fish culture dates back to 1940s in Cameroon, the lack of fingerlings has limited its development. Twenty-two fingerlings production centers have been constructed since 1960 (Folack et al. 2000). Yet for lack of continuous financial support and incentives, these centers have been abandoned (N. Jock 1994). Since the 1970s, other projects have been implemented in order to revitalize fingerlings production and aquaculture activities as a whole. However, results obtained from these projects have not reached and/or have not been adopted by fish farmers (N. Jock

1994). In a recent report (FAO 2000b; Folack et al. 2000), Cameroon acknowledged 10 stations and 22 hatcheries; yet most of these are presently quasi-abandoned.

There were about 2 000 fish farms for a total pond area of 250 ha in Ghana (Ofori 2000). About 50 per cent of the farmers abandoned their ponds for various reasons such as the absence of credit, unavailability of high quality fingerlings, inappropriate siting, and poor construction of ponds, and lack of suitable extension materials. Countries such as Mali are developing hatcheries. Three have been established for Nile tilapia (*Oreochromis niloticus)* fry production to strengthen the existing fish farming potential (Niaré et al. 2000).

Rearing Facilities

The development of aquaculture requires minimum facilities. In most advanced countries, several types of rearing facilities are used. These include earthen ponds, floating cages, enclosures, concrete tanks, and raceways. The utilization of concrete tanks and raceways is less widespread in Africa. They are generally found in specialized institutions such as research or production stations. In Côte d'Ivoire the most widespread structures are earthen ponds and floating cages in lagoons. Land access rights are becoming more and more difficult in many countries. Raising fish in floating cages should, therefore, be developed in the future. In Mali, a landlocked West African Country (Niaré et al. 2000), rearing facilities varied markedly from natural depressions within the Central Delta of the Niger River to fish ponds built within irrigation canals, and holes where earth has been removed for some purposes (i.e., dikes, road constructions). Integrated agriculture–aquaculture such as rice-cum-fish, vegetable-cum-fish, pig-cum-fish, and poultry-cum-fish culture are practiced (Ofori 2000). Fish culture in rice fields produced about 2 000 t of fish in 1988 in Egypt (FAO 1997b). The most commonly raised fish are the tilapias, common carp (*Cyprimus carpio*), and catfish (*Clarias gariepinus* or their hybrid).

Research Institutions

Various institutions have been given the mandate to conduct research in fisheries and aquaculture (FAO 1997a,b). Some of them are listed in Table 1 and other selected examples follow. In Côte d'Ivoire, the Oceanographic Research Centre (CRO), Fish Research Station of CNRA (Centre National de Recherche Agronomique), and the Universities of Cocody and Abobo-Adjamé conduct research on fish biology, reproduction, and taxonomy. The genetic aspect focuses on population genetics (Yapi-Gnaoré 2001). Fish related research has always been orientated towards increasing production, reducing production costs and other industrial aquaculture problems (Elghobashy 1997). Sufficient research on fish genetics is lacking.

Nigeria has many institutions for the capacity building of human resources (Stella Williams, personal communication). There are two universities of agriculture and several federally and state-funded universities and centers with scientific research activities on fish. These institutions are research centers for both freshwater as well as marine fisheries, and there are many other universities with facilities for fish culture and fisheries management. For example, the National Institute for Freshwater Fisheries Research (NIFFR) located centrally in New Bussa, Niger State (formerly known as the Kainji Lake Research Institute) and the National Institute for Oceanographic and Marine Research (NIOMR) located near the Atlantic coast in Lagos are under the supervision of the Federal Ministry of Agriculture, Water Resources and Rural Development.

Feed Availability

Agricultural and industrial by-products to feed fish are locally available. Commercial feed manufacturing companies exist in countries such as Côte d'Ivoire, Nigeria, South Africa, and Zimbabwe (FAO 2000b). Feed manufacturers such as FACI and Qualigrain in Côte d'Ivoire provide the necessary feed, but sometimes at high cost for small-scale rural fish farmers. The use of local industrial by-products in the formulation of feed rations will certainly reduce the cost.

Human and Administrative Resources

Management and Administration

In the majority of countries, the management and administration of the aquaculture sector are associated with that of fisheries. Aquaculture has been assigned to a great variety of institutional homes: Ministry of Agriculture, with forestry or livestock agencies; even with the Ministry of Natural Resources and Tourism in the case of

Table 1. Research and training institutions in fisheries and aquaculture (adapted from FAO 1997a,b).

Countries	Institutions
Egypt	• Alexandria Fish Technology Centre (FTC) • Oceanography Department (Faculty of Science), Alexandria University • Agricultural Research Centre (ARC), Food Technology Institute, Ministry of Agriculture • Inland and Aquaculture Branch, National Institute of Oceanography and Fisheries • Central Laboratory for Aquaculture, Ministry of Agriculture • General Authority for Fisheries Resources Development (GAFRD) • Food Sciences and Technology Department (Faculty of Agriculture), Menia University • Faculty of Agriculture, Food Science and Technology Department, University of Cairo • Edku Agriculture Secondary School
Nigeria	• African Regional Aquaculture Center, Port Harcourt • Department of Fisheries, Lagos State University • Department of Wildlife and Fisheries Management, University of Ibadan • Department of Zoology, University of Ibadan • Faculty of Agriculture, University of Nigeria, Nsukka • Faculty of Agriculture, University of Benin • Faculty of Agriculture, Obafemi Awolowo University, Ife • Faculty of Sciences, Imo State University • Faculty of Sciences, Lagos State University • School of Agriculture and Agricultural Technology, Rivers State University of Sciences and Technology • Federal University of Agriculture • Institute of Oceanography, Cross River State University, Calabar • University of Agriculture, Abeokuta • National Institute for Freshwater Fisheries Research, New Bussa, Niger State • National Institute for Oceanographic and Marine Research, Lagos
Ghana	• Institute of Aquatic Biology, Water Research Institute • University of Science and Technology, Kumasi • University of Ghana, Legon
Côte d'Ivoire	• Institut National de la Formation Professionnelle Agricole • National Polytechnique – Houphouët Boigny, Ecole Supérieure Agronomique • Université de Cocody • Université d'Abobo - Adjamé • Université de Bouaké, UFR de Korhogo • Centre National de Recherche Agronomique (CNRA)

Tanzania (FAO 2000b). Table 2 indicates the various administrative institutions in charge of the aquaculture in some African countries.

Extension Services

Aquaculture is not a traditional activity in most African countries, with the exception of Egypt (FAO1997a). Production techniques are not very well mastered by fish farmers and there is a need to assist fish farmers and promote fish farming.

Research and extension services are often under different ministries. This separation creates some difficulties in the coordination of activities. In some countries, integration of aquaculture and fisheries extension services has been initiated, for example in Mozambique, Tanzania, and Zambia (Andreason 1996).

Various institutes and centers in Nigeria carry out extension activities in liaison with the federal and state ministries, primary producers, industries and other users of research results in collaboration with Agricultural Extension and Rural Linkage Services (AERLS) at several universities. They also provide laboratory and other technical services to fish farmers, industries and others concerned with fresh and marine fisheries problems (Stella Williams, personal communication).

Training in Broodstock Management and Genetic Enhancement

Training centers for fisheries management and aquaculture development have been established in several countries (FAO 1977a,b), under the supervision of a state administrative structure

(Table 2). These specialized centers train agents at technician level. In most countries, there are no specialized academic institutions to train at the graduate or post-graduate levels, particularly in genetic enhancement, with the exception of Egypt, Malawi, and Nigeria. There is a great need for training in various aspects of fish genetics. Table 1 presents a list of institutions that have the potential for providing training in genetic enhancement in Africa, either academic training for a degree or on practical aspects.

The number of scientists may have increased over the last decade, but not in fish genetics as related to stock management and enhancement. International Network on Genetics in Aquaculture (INGA) coordinated by WorldFish Center has been training African scientists in quantitative genetics applied to aquaculture (Gupta and Acosta 2001). The number of trainees up to M.Sc. level in Malawi increased from two in 1973-88 to 14 in1988-93. This increase was the result of the implementation of aquaculture projects (Kaunda 1994). The research institutes and universities in Nigeria carry out capacity building of human resources under the auspices of NIOMR. They provide technical and vocational training in fresh and marine fisheries and related fields leading to the award of national diplomas. Many Africans have been trained in aquaculture in this institute and are still being trained there (Stella Williams, personal communication).

Genetic Enhancement Programs: Planned Fish Breeding

Long-term government policies towards genetic enhancement are lacking, perhaps because of the false general belief that watersheds are full of fish that can be harvested at no cost. Therefore, there is no need to bother with genetic improvement of the cultured stocks. Despite the existence of physical facilities, the lack of funds as well as qualified and specialized personnel, and the lack of long-term commitment in genetic enhancement hinder research efforts. One major constraint to undertaking genetic development is the irregularity of financial support. Consequently, very few genetic enhancement programs and fish breeding programs exist or are planned, except for the activities undertaken by INGA member countries including Côte d'Ivoire, Egypt, Ghana, and Malawi (Ambali 2001; Elghobashy 2001; Gupta and Acosta 2001; Yapi-Gnaoré 2001). These activities involved the evaluation of local strains for the selective breeding of *O. niloticus* in Côte d'Ivoire, Egypt, Ghana, and *O. shiranus* in Malawi.

Fish genetic research in Egypt has a relatively short history. The main topics were related to electrophoresis studies and the effect of salinity on gene expression in tilapia (Elghobashy 1997). Genetic enhancement of Egyptian farmed tilapia under different environmental and culture conditions is underway using four strains of *O. niloticus*. The selection program in government hatcheries in Egypt is for growth, DNA fingerprinting, and gene transfer and other genetic work (Elghobashy 2001). In Malawi, the wild populations of *O. shiranus* were selected along with domesticated fish using mass selection for growth. Selected populations grew faster than unselected ones (Ambali 2001). In Côte d'Ivoire, wild populations of *O. niloticus* have been collected from three different locations,

Table 2. Administrative bodies in charge of aquaculture in some countries (adapted from FAO 1997a,b).

Description	Reference Point
Cameroon	Ministry of Livestock, Fishery and Animal Husbandry
Côte d'Ivoire	Ministère de l'Agriculture et des Ressources Animales Ministère de l'Enseignement Supérieur et de la Recherche Scientifique
Egypt	General Authority for Fish Resources Development National Institute of Oceanography and Fisheries
Ghana	Ministry of Food and Agriculture
Kenya	Ministry of Tourism and Wildlife
Madagascar	Ministère de l'Elevage et des Ressources Halieutiques
Malawi	Ministry of Forestry and Natural Resources
Mozambique	Secretariat of State for Fisheries
Nigeria	Federal Ministry of Agriculture, Water Resources and Rural Development
Rep. South Africa	Ministry of Environment Affairs
Tanzania	Prime Ministry and Ministry of Tourism, Natural Resources and Environment
Zambia	Ministry of Agriculture, Food and Fisheries

and are being compared with populations kept on station for growth traits (i.e., body length and weight), feed conversion ratio and survival rate. The best performing families will serve as the base population for a selective breeding program.

Mair and Beardmore (2001) reported a collaborative three-year project between the University of Wales, Swansea and the University of Stellenbosch, South Africa on genetic characterization and the application of the YY males technology to indigenous strains of *O. mossambicus*. Research work on combined selection, QTL mapping and marker-assisted selection of *O. niloticus* in Africa has been undertaken by Auburn University in collaboration with the WorldFish Center (Liu 2001). Microsatellite markers have been developed and fish samples are being genotyped.

Risk Assessment

Risk of Fish Transfer

The possibility of risk to biodiversity conservation by involuntary or accidental dissemination of exotic or improved fish species is a real concern. Hybridization in the natural environment among tilapia species is well documented. A species is never stable in nature. It may die out or spread to other species (Thys van den Audenaerde 1988). In the Itasy lake of Madagascar, *O. macrochir* and *O. niloticus* introduced in the sixties hybridized to produce the so-called three-quarter tilapia. This population was maintained for many years along with the parental species (Daget and Moreau 1981). Recently hybridization in their natural habitat between *Tilapia zillii* and *T. guineensis* has been observed in the lake of Ayamé, a man-made lake in Côte d'Ivoire (Paugy and Levèque 1999). Another example of hybridization was observed among three species of Cichlidae (*T. zillii, T. guineensis,* and *T. dageti*) in the Comoé River in Côte d'Ivoire (Paugy and Levèque 1999).

Tilapia culture that started in Belgian Congo (Shaba region) led to some species being transferred to southern Morocco in the 1920s, but the natural and ecological barriers stopped the spread further south. *O. niloticus* was first raised in 1956 to replace *O. macrochir*. Uncontrolled transfers of tilapia continue throughout Africa, many of which have been undocumented (Thys van den Audenaerde 1988). Hybridization with translocation in man-made lakes, unintentional translocation, and introduction for biological control constituted threats to the integrity of wild tilapia. The lack of control over breeding and stocking results in over-population, hybridization, and stunting of fish stocks (Van der Bank 1997). The construction of dams may lead to a species replacement, as in the example where *Sarotherodon melanotheron* replaced *O. niloticus* as a landlocked population in the Ayamé in Côte d'Ivoire (Ouattara et al. 2000).

Evaluation Methods

New technologies are available to document genetic resources and provide a means to evaluate the transfer of species and pedigree analysis. These include nuclear and mitochondrial DNA analyses (DNA sequencing, mini and micro-satellites, DNA fingerprinting, RFLP, and isozyme analysis) (Pullin 1988). Blood group typing provided a useful technique to discriminate between closely related species and between domesticated (or inbred) and wild populations within a species (Willwock 1988). DNA fingerprinting has been used recently to document the status of wild and cultured stocks (Pullin 1988) and to trace the history of native stocks of tilapia in Egypt (Elghobashy 1997). Isozyme study has been used to assess genetic variation and differentiation of tilapia species in southern Africa (Van der Bank 1997). Micro-satellite DNA analysis is useful to study genetic relationships between populations (Ambali and Doyle 1997) and allozymes have been studied to determine phylogenetic relationships (Agnèse et al. 1997).

There is a need to set up indicators that can be monitored and evaluated regularly. The knowledge of genetic resources is a way to optimize production and to manage broodstocks more effectively and evaluate genetic enhancement programs. The knowledge of the genetic structure of populations (Pullin and Casal 1996) will be useful for: harvest quota setting; minimizing risk of species transfer; choosing appropriate species for fishery enhancement; and identifying and managing species that may be at risk.

An efficient monitoring and environmental impact assessment will require the collaboration with advanced institutions, networking with other countries for the development of common and trans-boundary projects, the sharing of comparative advantages in using existing infrastructures within Africa and the development of a long-term work program. To accomplish this, the institutes and universities should collaborate with other relevant research institutes and organizations.

Dissemination of Risk Information

In addition to regular communication media (such as radio, TV, leaflets, etc.), modern information technology can be used to disseminate information (i.e., relational database that will be regularly up-dated, CDROM, and the Internet). Rural radios are becoming widespread in various African countries. These technologies will make the information accessible to the general public. However, to be effective, there is the need for public awareness, participation, and support (Pullin 1997).

Quarantine and Health Management Procedures

Potential pathogen transfer should be avoided/ minimized and fish health should be ensured by following international protocols and guidelines during transfers. Some examples of such guidelines and protocols developed include Asia Regional Technical Guidelines (FAO/NACA 2000) and the ICES (1995) codes of practice that were developed for Europe and North America. A precautionary approach in work that involves fish introduction and transfer should be adopted (Pullin and Bartley 1996; Bartley and Minchin 1997). A health certificate should be required before any transfer to ensure that the germplasm is healthy and will not introduce pathogens to the new habitat. All transfers must be done following an appropriate risk analysis. Any transfer should be well documented.

Legislation

Andreasson (1996) reviewed legislation in 12 Sub-Saharan African countries; only three countries (Kenya, Madagascar, and Nigeria) had specific aquaculture legislation. Three others countries (Malawi, Tanzania and Zimbabwe) have limited legislation for the introduction of exotic species. Six others had no specific aquaculture legislation. Existing legislation was more concerned with conservation as related to water abstraction, pollution, and water rights. When permits or licenses are granted, they are related to land, water, and environmental factors. The legislation document proposed in Côte d'Ivoire concerned only fisheries (Nugent 1997). Reviews conducted in ten SADC (Southern African Development Community) countries in Southern Africa by ALCOM (Aquaculture for Local Community Development) showed that most governments in the region did not have any explicit development policy or plan for aquaculture, consequently by extension for fish transfer (FAO 2000b). Conservation institutions such as International Fisheries Gene Bank - IFGB (Harvey 1996), along with international organizations (FAO WorldFish Center) can assist governments to develop policies in collection and exchange of fish genetic material. The community-based farmer participatory approach is often recommended. However, communal management practices may not be sustained because of lack of incentives and disputes over rights to harvest. Kinship relations may play a more important role in determining rights and responsibilities.

Conclusion

Nearly every African country except eight (Chad, Djibouti, Eritrea, Equatorial Guinea, Guinea Bissau, Mauritania, Somalia, and Western Sahara) has developed some aquaculture production program since the organization of the first African workshop on aquaculture planning in 1975 (FAO 2000b). At that time, the situation was characterized by:

- Little government support for aquaculture;
- Abandonment of fish culture stations and hatcheries;
- Abandonment of private fish ponds;
- Shortage of fish feed and fish seed;
- Shortage of field staff;
- Lack of access to available aquaculture information; and
- Lack of reliable aquaculture statistics.

Aquaculture is known today throughout the continent as a result of extension efforts, but failed to achieve the expectations, and the prevailing situation remains almost the same as it was 25 years ago. Priority for development funds and coherent national plans for aquaculture, particularly for fish enhancement, are still lacking.

Aquaculture, and particularly tilapia culture, has an important role to play in African development. However, all partners (government authorities, research organizations, and parastatals), and non-government organizations (NGO, farmers' organizations, private companies, and private producers) should be involved in the decision-making processes in order to create an appropriate environment for sustainable genetic improvement programs for tilapia in Africa.

References

Abban, E.K., C.M .V. Casal, T.M. Falk and R.S.V. Pullin (eds.) 2000. Biodiversity and sustainable use of fish in the coastal zone. ICLARM Conf. Proc. No. 63, 71 p.

Agnèse, J.-F., B. Adépo-Gourène and L. Pouyaud. 1997. The utilization of allozymes to study population of tilapias, p. 46-56. ***In*** Pullin, R.S.V., C.M.V. Casal, E.K. Abban and T.M. Falk (eds.) Characterization of Ghanaian tilapia genetic resources for use in the fisheries and aquaculture. ICLARM Conf. Proc. No. 52, 58 p.

Ambali, A.J. 2001. Aquaculture genetics research in Malawi, p. 61-64. ***In*** Gupta, M.V. and B.O. Acosta (eds.) Fish genetic research in member countries and institutions of the International Network on Genetics in Aquaculture. ICLARM Conf. Proc. No. 64, 197 p.

Ambali, A.J. and R.W. Doyle. 1997. Genetic characterization of Malawian tilapia, p. 29-30. ***In*** Pullin, R.S.V., C.M.V. Casal, E.K. Abban and T.M. Falk (eds.) Characterization of Ghanaian tilapia genetic resources for use in the fisheries and aquaculture. ICLARM Conf. Proc. No. 52, 58 p.

Andreason, A. 1996. The institutional context, p. 119-143. ***In*** FAO's 1996 Report of the expert consultation on small-scale rural agriculture. FAO Fisheries Report No. 548, 182 p.

Bartley, D.M. and D. Minchin. 1997. Precautionary approach to species introductions. Sweden/FAO Fisheries Technical Paper No. 350/2:159-189.

Daget, J. and J. Moreau. 1981. Hybridation entre deux espèces de *Sarotherodon* (Pisces, Cichlidae) dans un lac de Madagascar. *Bull. Mus. Natn. Hist. Nat.,* Paris, 4, 3A, 2: 689–703.

Diallo, A. 1997. Biodiversity and genetics of farmed tilapias in Sénégal, p.15-16. ***In*** Pullin, R.S.V., C.M.V. Casal, E.K. Abban and T.M. Falk (eds.) Characterization of Ghanaian tilapia genetic resources for use in the fisheries and aquaculture. ICLARM Conf. Proc. No. 52, 58 p.

Elghobashy, H., 1997. Fish genetics in Egypt, p. 14. ***In*** Pullin, R.S.V., C.M.V. Casal, E.K. Abban and T.M. Falk (eds.) Characterization of Ghanaian tilapia genetic resources for use in the fisheries and aquaculture. ICLARM Conf. Proc. No. 52, 58 p.

Elghobashy, H. 2001. Aquaculture genetics research in Egypt, p. 29-34. ***In*** Gupta, M.V. and B.O. Acosta (eds.) Fish genetic research in member countries and institutions of the International Network on Genetics in Aquaculture. ICLARM Conf. Proc. No. 64, 197 p.

Ezenwa O.I.B. 1994. Aquaculture development and research in Nigeria. ***In*** Aquaculture development and research in Sub-Saharan Africa, national review. FAO, CIFA Technical Paper 23 Suppl., 41–105.

FAO. 1997a. Review of the state of world aquaculture. FAO Fisheries Circular No. 886, Rev. 1, 163 p.

FAO. 1997b. Directory of African capacities in fisheries. RAF publication RAF1/97/01, CIFA Technical Paper Series, Vol. III, 669 p.

FAO.2000a. La situation mondiale des pêches et de l'Aquaculture. www.fao.org/DOCREP/003/x8002E/x802E04. htm#P1_6.

FAO. 2000b. Africa regional aquaculture review Proceeding of a workshop held in Accra, Ghana, 22–24 September 1999. CIFA occasional paper No. 24, 50 p.

FAO/NACA. 2000. Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals and the Beijing Consensus and Implementation Strategy. FAO, Rome and NACA, Bangkok. 38 p.

Folack, J., C.E. Gabche and G.Y. Chiambeng. 2000. Fish culture potential and biodiversity conservationin the Cameroon coastal zone, p. 44-47. ***In*** Abban, E.K., C.M .V. Casal, T.M. Falk and R.S.V. Pullin (eds.) Biodiversity and sustainable use of fish in the coastal zone. ICLARM Conf. Proc. No. 63, 71 p.

Gupta, M.V. and B.O. Acosta. 2001. Networking in aquaculture genetics research, p. 1-5. ***In*** Gupta, M.V. and B.O. Acosta (eds.) Fish genetic research in member countries and institutions of the International Network on Genetics in Aquaculture. ICLARM Conf. Proc. No. 64, 197 p.

Harrison, E. 1996. Options for small-scale aquaculture development, p. 33-68. ***In*** FAO, 1996. Report of the expert consultation on small-scale rural agriculture. FAO Fisheries Report No. 548.

Harvey, B.J. 1996. Ex situ genetic conservation and policy development at the International Fisheries Gene Bank, p. 29. ***In*** Pullin, R.S.V. and C.M.V. Casal (eds.) Consultation on fish genetic resources. ICLARM Conf. Proc. No. 51, 61 p.

ICES. 1995. ICES Code of Practice on the Introductions and Transfers of Marine Organisms. International Council for the Exploration of the Sea, Copenhagen, Denmark. 5 p.

Kaunda, E.K. 1994. Aquaculture in Malawi: the past, present and future – a brief overview, p. 5-6. ***In*** Brummett, R.E. (ed.) Aquaculture policy options for integrated resource management in Sub-Saharan Africa. ICLARM Conf. Proc. No. 46, 38 p.

Liu, Z. 2001. Gene mapping, marker-assisted selection, gene cloning, genetic engineering and integrated genetic improvement programs at Auburn University, p. 109-118. ***In*** Gupta, M.V. and B.O. Acosta (eds.) Fish genetic research in member countries and institutions of the International Network on Genetics in Aquaculture. ICLARM Conf. Proc. No. 64, 197 p.

Mair, G.C. and J.A. Beardmore. 2001. Research on the genetics of aquatic organisms at the School of Biological Sciences, University of Wales, Swansea, p. 151-159. ***In*** Gupta, M.V. and B.O. Acosta (eds.)

Fish genetic research in member countries and institutions of the International Network on Genetics in Aquaculture. ICLARM Conf. Proc. No. 64, 197 p.

Nguenga, D. 1988. The status of wild and cultured tilapia genetic resources in various countries: Cameroon, p. 19. ***In*** Pullin, R.S.V. (ed.) Tilapia genetic resources for aquaculture. ICLARM Conf. Proc. No. 16, 108 p.

Niaré, T., B. Kassibo, and J. Lazard. 2000. What farming development model for Mali, where traditional inland fisheries thrive? *Cahiers d'Etudes et de Recherche Francophones/Agricultures. 9(3)*:173-179.

N'Jock, J.C. 1994. Développement et recherche aquacoles au Cameroun: ***In*** Aquaculture development and research in Sub–Saharan Africa: National Review; FAO, CIFA Technical Paper No. 23 Suppl., 81–103.

Nugent, C.G. 1997. Raport sur l'aménagement des pêches continentales: assistance en matière de législation portant sur les pêches continentales. FAO Programme de Coopération Techniques. 86 p.

Ofori, J.K. 2000. Status and trends in integrated agriculture-aquaculture in Ghana, p. 36-37. ***In*** Abban, E.K., C.M .V. Casal, T.M. Falk and R.S.V. Pullin. (eds.) Biodiversity and sustainable use of fish in the coastal zone. ICLARM Conf. Proc. No. 63, 71 p.

Ouattara, N.I., G.G. Teugels and J.C. Philippart. 2000. Aquaculture potential of a landlocked population of the black-chinned tilapia, *Sarotherodon melanotheron*, in artificial lake (Lake Ayamé) in Côte d'Ivoire, p. 41-43. ***In*** Abban, E.K., C.M .V. Casal, T.M. Falk and R.S.V. Pullin. (eds.) Biodiversity and sustainable use of fish in the coastal zone. ICLARM Conf. Proc. No. 63, 71 p.

Paugy, D. and C. Lévèque. 1999. Taxinomie et systématique, p. 99-119. ***In*** C. Lévèque and D. Paugy (ed.) Les poissons des eaux continentales africaines. Editions de l'IRD, Paris.

Pedini, M. 2000. Bridging the gap: Can aquaculture meet the additional demand for fishery products? FAO Aquaculture Newsletter (FAN), April 2000, No. 24.

Planquette, P. and C. Petel. 1977. Données sur la production en masse d'alevins de *Tilapia nilotica*. Notes et Documents sur la pêche et la pisciculture, No., 14:1–6.

Pullin, R.S.V. 1988. Research methods used in tilapia identification and genetic research: electrophoresis, p. 53. ***In*** Pullin, R.S.V. (ed.) Tilapia genetic resources for aquaculture. ICLARM Conf. Proc. No. 16, 108 p.

Pullin, R.S.V. and D.M. Bartley. 1996. Biosafety and fish genetic resources,p. 33-35. ***In*** Pullin, R.S.V. and C.M.V. Casal (eds.) Consultation on fish genetic resources. ICLARM Conf. Proc. No. 51, 61 p.

Pullin, R.S.V. 1997. International concerns on fish biodiversity and genetic resources management, p.1-2. ***In*** Pullin, R.S.V., C.M.V. Casal, E.K. Abban and T.M. Falk (eds.) Characterization of Ghanaian tilapia genetic resources for use in the fisheries and aquaculture. ICLARM Conf. Proc. No. 52, 58 p.

Pullin, R.S.V. and C.M.V. Casal (eds.) 1996. Consultation on fish genetic resources. ICLARM Conf. Proc. No. 51, 61 p.

Subasinghe, R.P. 1996. Health certification and quarantine of aquatic organisms: practical guidelines for Asia and the Pacific. FAO Aquaculture Newsletter (FAN), April 1996, No. 12:10-13.

Thys van den Audenaerde, D.F.E. 1988. Natural distribution of tilapias and its consequences for the possible protection of genetic resources, p. 1-11. ***In*** Pullin, R.S.V. (ed.) Tilapia genetic resources for aquaculture. ICLARM Conf. Proc. No. 16, 108 p.

Van der Bank, F.H. 1997. Tilapia biodiversity, genetic resources conservation and sustainable use: a South African perspective, p. 19-20. ***In*** Pullin, R.S.V., C.M.V. Casal, E.K. Abban and T.M. Falk (eds.) Characterization of Ghanaian tilapia genetic resources for use in the fisheries and aquaculture. ICLARM Conf. Proc. No. 52, 58 p.

Willwock, W. 1988. Research methods used in tilapia identification and genetic research: research on tilapia blood groups, p. 55-56. ***In*** Pullin, R.S.V. (ed.) Tilapia genetic resources for aquaculture. ICLARM Conf. Proc. No. 16, 108 p.

Yapi-Gnaoré, C.V. 2001. Fish genetic research in Côte d'Ivoire, p. 25-28. ***In*** Gupta, M.V. and B.O. Acosta (eds.) Fish genetic research in member countries and institutions of the International Network on Genetics in Aquaculture. ICLARM Conf. Proc. No. 64, 197 p.