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Proceedings of a Workshop on the Development of a Genetic Improvement Program for African Catfish *Clarias gariepinus*

Edited by R.W. Ponzoni and N.H. Nguyen

WorldFish CENTER

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Proceedings of a Workshop on the Development of a Genetic Improvement Program for African Catfish *Clarias gariepinus*

Accra, Ghana, 5-9 November 2007

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The WorldFish Center is one of the 15 international research centers of the Consultative Group on International Agricultural Research (CGIAR) that has initiated the public awareness campaign, Future Harvest.

CONTENTS

LIST OF ABBREVIATIONS AND ACRONYMS

ADB	Agriculture Development Bank, Ghana
ADCP	African Development Center for Aquaculture
ADiM	Aquaculture Development in Malawi
AFWA	African Water Association, Kenya
AGCD	General Administration for Cooperation and Development, Belgium; (Administration Générale de la Coopération au Développement)
AgSSIP	Agricultural Sub-sector Capacity Building Project, Ghana
AIFP	Aquaculture and Inland Fisheries Project, Nigeria
ARAC	African Regional Aquaculture Center
ARDC	Aquaculture Research and Development Center, Kajjansi, Uganda
ARDEC	Aquaculture Research and Development Center, Akosombo, Ghana
BOMOSA	Research project pioneering small-scale fish farming in three countries in East Africa: Ethiopia, Kenya and Uganda
CEPID	Center of Excellence for Production Innovation and Development; (Centre d'Excellence pour la Production l'Innovation et le Développement)
CFA	Communauté Financière Africaine (African Financial Community)
CID	Commercialization and Information Division
CIFA	Central Institute of Freshwater Aquaculture
CIP	Construction des Innovations en Partenariat
CLOFFA	Checklist of the Freshwater Fishes of Africa
CRIRP	Project of the Foundation for Research Development (CRIR) at the University of Pretoria, South Africa
CSIR	Council for Scientific and Industrial Research, Ghana
DFID	U.K. Department for International Development, London
DIRPEC	Department of Fisheries of MINEPIA, Cameroon
DOCA	Desoxycorticosterone acetate
DOF	Directorate of Fisheries, Ghana (former name of Ministry of Fisheries)
EAC	East African Community
EAD	Environmental Affairs Department, Malawi
EEZ	Exclusive economic zone
EU	European Union, Brussels, Belgium
FAO	Food and Agriculture Organization of the United Nations, Rome, Italy
FCFFT	Federal College of Freshwater Fisheries Technology, New Bussa and Baga, Nigeria
FCFMT	Federal College of Fisheries and Marine Technology, Lagos, Nigeria
FD	Fisheries Department, Kenya
FISH	Fisheries Investment for Sustainable Harvest (a USAID-funded project in Uganda implemented by Aurban University)
FPC	Fry production center, Kenya
GAFRD	General Authority for Fisheries Resources Development, Egypt
G x E	Genotype by environment (or genotype x environment)
GIFT	Genetically improved farmed tilapia
IAA	Integrated aquaculture-agriculture
IAB	Institute of Aquatic Biology, Ghana (former name of the present CSIR-WRI)
ICLARM	International Center for Living Aquatic Resources Management (now The WorldFish Center)

IDRC	International Development Research Centre, Ottawa, Canada
IFC	International Finance Cooperation
IITA	International Institute of Tropical Agriculture, Cameroon
IMF	International Monetary Fund, Washington, D.C.
INGA	International Network on Genetics in Aquaculture
IRAD	Institute of Agricultural Research for Development, Cameroon (Institut de Recherche Agricole pour le Développement de Cameroun)
JICA	Japanese International Cooperation Agency, Tokyo
KMFRI	Kenya Marine and Fisheries Research Institute
KNUST	Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
KUL	Katholieke Universiteit Leuven, Belgium
LBDA	Lake Basin Development Authority, Kenya
MAAIF	Ministry of Agriculture, Animal Industries and Fisheries, Uganda; (Ministère de l'Agriculture, des Industries Animales et des Pêches de Uganda)
MALDECO	Private company producing tilapia feed in Malawi
MINEPIA	Ministry of Livestock, Fisheries and Animal Industries, Cameroon; (Ministère de l'Élevage des Pêches et des Industries Animales de Cameroun)
MINRESI	Ministry of Scientific Research and Innovation, Cameroon; (Ministère de la Recherche Scientifique et de l'Innovation de Cameroun)
MoFi	Ministry of Fisheries, Ghana (formerly the Directorate of Fisheries)
NARES	National aquatic research and extension systems
NARS	National aquatic research system
NEPAD	New Partnership for Africa's Development
NGO	Non-governmental organization
NIFFR	National Institute for Freshwater Fisheries Research, New Bussa, Nigeria
NIOMR	Nigerian Institute for Oceanography and Marine Research
NSPFS	Nigerian Special Programme for Food Security
NUVITA	Private company manufacturing fish feeds for one fish farm (Source of the Nile) in Uganda
ORSTOM	Office de la Recherche Scientific et Technique Outre-Mer, Paris, France
PNVRA	National Agricultural Research and Extension Program, Cameroon
PPP	Public-private partnership
R & D	Research and development
RDE	Research, development and extension
REPARAC	La Recherche Agronomique au Cameroun
SEAPB	Service d'Études et d'Appui aux Populations à la Base (NGO in Cameroon)
SME	Small and medium-sized enterprises
SSA	Sub-Saharan Africa
TOT	Training of trainers
UNDP	United Nations Development Programme, New York
USAID	United States Agency for International Development, Washington, D.C.
World Bank	The World Bank, Washington, D.C.
WorldFish	The WorldFish Center, Penang, Malaysia (formerly ICLARM)
WRI	Water Research Institute, Ghana
WRRI	Water Resources Research Institute, Ghana (former name of WRI)
WRS	Water recirculation system

Note: All references to dollars ($) in this publication refer to US dollars.

FOREWORD

In recent years African catfish (*Clarias gariepinus*) production has gained considerable importance in a number of countries on the continent. The species has several desirable attributes that make it attractive when aquaculture development is considered. It is highly suitable for farming because it is easy to reproduce, it does not require specialized feed, it tolerates high stocking densities and grows rapidly under these conditions, it accepts artificial feed, it tolerates poor water quality, and very importantly, it is highly sought after in local markets and economically viable in pond production systems. *Clarias gariepinus* is endemic to Africa.

Following consultation with African partners The WorldFish Center organized a workshop on the specific topic 'Development of a genetic improvement program for catfish – *Clarias gariepinus*'. The workshop was held from 5 to 9 November 2007 in Accra, Ghana. The Water Research Institute (WRI) was the host organization in Ghana.

The participants at the workshop were persons directly involved in work with the species. Both government and non-government personnel were invited to attend and were present at the workshop.

The workshop objectives were as follows:

1. To review the state of the catfish industry in Africa (participants were asked to make a presentation on the state of the industry in their own country)
2. To present a series of keynote papers in the areas of:
   Catfish reproductive management and grow out
   Catfish nutrition and feeds
   The application of genetic principles to catfish genetic improvement programs
3. Based on the information presented above the participants were encouraged to develop recommendations on how to best approach the issue of genetic improvement programs for catfish. These recommendations have been consolidated in the present workshop proceedings, and they will be used in the future to jointly develop proposals on the establishment of catfish genetic improvement programs in Africa. We are delighted to present these proceedings to you.

Finally, we would like to use the opportunity to thank the Water Research Institute (Council for Scientific and Industrial Research) for hosting the workshop in Accra, Ghana. In particular, we would like to thank Dr Felix Attipoe and Mr Seth Agyakwa for their extraordinary input into the organization of the event and for the hospitality they displayed during the participants' stay in Ghana. Funding for the workshop was provided by the European Union (EU).

Dr Raul W. Ponzoni Dr Nguyen Hong Nguyen

INTRODUCTION

Clarias gariepinus is the second most important freshwater fish (after tilapia) in Africa — with the exception of Nigeria where production of African catfish far exceeds that of tilapia and accounts for 70–80 percent of the total freshwater fish production in the country. Despite the high potential for production of this species, the industry on this continent has not been well established, and is generally in a very immature stage. One of the critical limiting factors has been a serious lack of good quality seed to supply farmers and producers. This has resulted from the poor performance of available local brood stock and poor management practices at hatcheries, as well as the non-existence of any appropriate breeding structure or improved strains.

Other constraints that have resulted in low productivity of *C. gariepinus* in existing farming systems in Africa include difficulties with induced male reproduction, low survival rates during the larvae rearing stage, inefficient utilization of local feedstuff, lack of least-cost optimal balanced diets, poor management practices, and immature post-harvest (processing) industry and marketing systems. There are also concerns about the development of catfish production in relation to environmental protection, genetic resource conservation, genetic biodiversity, and the future sustainability of the industry.

In view of the current state of catfish production, and as part of a program of research and capacity building for aquaculture development in Africa, a workshop on "The development of a genetic improvement program for African catfish - *Clarias gariepinus*" was held in Accra, Ghana from 5 to 9 November 2007. Convened by the Water Research Institute (WRI) and the WorldFish Center, the workshop brought together participants from eight major catfish producing countries in Africa to discuss the technical constraints, the challenges and the opportunities that they face.

The workshop started with country reports presenting an overview of the current state of catfish production and research, and was followed by a series of keynote papers covering a wide range of topics from basic biology to modern genetic technologies suited to future selective breeding programs for this species. The workshop included a field trip to catfish farms and provided an open forum for group discussions. The program of the workshop is described in the following section.

THE WORKSHOP

THE WORKSHOP OPENING

The workshop was officially opened on the morning of Monday the 5th November 2007 by Dr. Yaw Opoku-Ankomah, Director General of the Council for Scientific and Industrial Research (CSIR) of Ghana. This was followed by introductory remarks by the chairman, Dr. Kwame Boa-Amponsem, Director of the Water Research Institute (WRI) (Annex D). Mr. Kofi Agbogah, a research scientist at WRI, facilitated the introduction of workshop participants before inviting the Director General of WRI to make the opening address.

Dr. Yaw Opoku-Ankomah welcomed the participants to CSIR-WRI, Ghana, and briefed them on the history, structure, organization and mission of CSIR-WRI. He also stressed the long-term cooperation between the WorldFish and CSIR-WRI. During the 1980s, CSIR-WRI played a very active role in providing tilapia germplasm for the genetically improved farmed tilapia (GIFT) project. The on-going genetic improvement program in local indigenous Nile tilapia at the Aquaculture Research and Development Center of WRI at Akosombo has been implemented with substantial inputs from the WorldFish Center. The improved "Akosombo" tilapia strain has gained popularity and is beginning to make a significant contribution to aquaculture in Ghana. Finally, Dr. Yaw Opoku-Ankomah expressed his appreciation to WorldFish for their partnership and support (Annex C).

Dr. Raul Ponzoni, Senior Scientist and Program Leader (Geneticist) of the WorldFish Center, thanked the Director General for his informative and supportive opening address before making some brief opening remarks. Dr. Ponzoni highlighted the workshop's objectives and agenda, the format for discussions in groups and for presentations (Annex D). He also noted some housekeeping rules and the workshop process. In particular, Dr. Ponzoni stressed the need to bring experts from partner countries in the region to the workshop, and its importance in identifying technical constraints encountered in the catfish industry. The inputs from the participants would be a pre-requisite for the formulation of recommendations to develop a regional program for genetic improvement in *C. gariepinus*. He also expected all participants to work hard and contribute their wealth of experience to achieve the workshop's objectives. Finally, Dr. Ponzoni wished the workshop to be fruitful and successful.

THE PARTICIPANTS

A total of 36 participants from research institutions, universities, departments of fisheries, and fish farmer associations from eight African countries (Cameroon, Egypt, Ghana, Kenya, Malawi, Nigeria, South Africa and Uganda) attended the workshop. The majority of the participants had a strong technical background and extensive experience in catfish research and production in their respective countries. Some participants came from other disciplines such as aquatic biology, aquaculture, economics, and business administration. A number of postgraduate students from Nigeria took the opportunity to attend the workshop. There were also experts from Israel and commercial fish producers from the Netherlands. A full list of participants and details of their correspondence addresses is provided in Annex A.

THE AGENDA

The workshop had the following three objectives:

i) To review the state of the catfish industry in Africa as well as research issues and future research priorities on *Clarias gariepinus*;
ii) To present a series of keynote papers in the areas of biology and genetic diversity of African catfish, production and reproduction management, catfish nutrition and feeds, the application of genetic principles to catfish genetic improvement programs, the WorldFish Center's genetic improvement program in Abbassa, Egypt, and potential application of molecular information and reproductive technologies in practical breeding programs; and

Participants at the workshop on the development of a genetic improvement program for African catfish *Clarias gariepinus* in Accra, Ghana 5-9 November 2007.

iii) To develop recommendations on how best to approach the issue of genetic improvement programs for catfish.

Details of the workshop agenda are given in Annex B. The main activities of the workshop included presentations of country reviews and reports, keynote papers, a one-day field trip, group discussions and a synthesized report under the format of WorldFish concept note development.

THE OUTPUTS

Overall, the workshop provided a very good opportunity to exchange information about the catfish industry in different African countries. There were also opportunities to exchange practical experiences with the invited speakers and among other participants. A one-day field trip allowed participants to visit farms and hatcheries, and get close to the real production environment. The group discussions which capped the workshop provided an ideal forum for the final debate and the formulation of recommendations regarding the activities to be undertaken for further progress. A brief concept note was also developed and distributed to all the participants. The recommendations emanating from the workshop will be used to jointly develop proposals on the establishment of catfish genetic improvement programs in Africa.

COUNTRY REVIEWS

The seven country reviews provide information on the current state of catfish production (by year and region within each country), the existing industry structure (scale and mode of production of breeding centers, hatcheries, and of catfish farmers and producers), existing production conditions and farming systems of African catfish, marketing structure, catfish products, post-harvest technology as well as the role of other sectors involved in the industry. In addition, past and current research in the area of biology, breeding and genetics, seed production, feeds and nutrition, and production management were discussed and given in the country reports. Representatives of each country also presented gaps, constraints, issues and research priorities that, in their view, needed addressing.

DISCUSSION FROM KEYNOTE SPEAKERS

The seven keynote speakers addressed a whole range of issues needed to develop a genetic improvement program for *Clarias gariepinus.* Highlighted areas included the taxonomy of the species, its distribution in Africa, biological characteristics, growth performance, reproductive management, culture systems, feed and nutrition, genetic principles for the design of breeding programs, dissemination strategies of improved fish, tagging, rearing and breeding methods, as well as potential applications of new technologies to maximize the efficiency of the breeding program and the economic benefits contributed to the national economies of African countries.

PRIORITY AREAS FOR FUTURE RESEARCH AND TRAINING

Based on the gaps, issues and constraints identified during the workshop, and on recommendations emanating from the country reports, the priority areas for future research and training were as follows:

- Development of a genetically improved strain of *C. gariepinus* adapted to a wide range of production environments in Africa;
- Construction or expansion of the existing national and regional networks of hatcheries to supply an adequate quantity of good-quality seed to farmers;
- Formulation of optimal low-cost diets based on local feedstuffs and resources or agricultural by-products;
- Establishment of training programs at both international and regional levels in order to enhance human and institutional capacity needed to undertake the genetic improvement of catfish;
- Development of appropriate socio-economic policies to promote aquaculture and catfish production;
- Development of a network of scientists and practitioners involved with catfish production and management.

OBJECTIVES AND OUTPUTS

The specific objectives and the achieved outputs of the workshop are summarized in Table 1.

CLOSING REMARKS

The workshop was officially closed by Dr. Raul Ponzoni of the WorldFish Center. Dr. Ponzoni summarized the key achievements and highlighted the progress made during the five-day workshop. He expressed his sincere thanks to all participants for their time, participation and contributions, and acknowledged the support of the Council for Scientific and Industrial Research (CSIR) of Ghana, and particularly the staff of the Water Research Institute (WRI) for their preparation, organization, warm welcome and hospitality throughout the workshop. Dr. Ponzoni reiterated that the WorldFish Center would make every effort to promote the application of the findings of the meeting and to assist in seeking means to pursue the concept note proposal and the recommendations of the workshop; however, he emphasized that this was a shared responsibility of all countries involved in future programs.

Dr. Felix Attipoe from the Water Research Institute (WRI) thanked the WorldFish Center for their dedication and efforts to make the workshop successful. He also commented

Table 1: The workshop objectives and outputs

	Objectives	Outputs
1	To review the state of catfish production and research in African countries	• Overview of current state and trends of catfish production in African countries • Overview of research undertaken in the areas of biology, breeding and genetics, nutrition and culture management
2	To identify gaps, constraints and issues in catfish production	• Lack of improved strains adapted to existing farming environments in Africa • Poor or non-existent network of hatcheries to multiply or produce good quality seed and brood stock to supply farmers and producers • Production of low-cost diets based on local feedstuffs and agricultural resources • Socioeconomic policies to promote aquaculture and catfish
3	To understand the biology, genetic diversity, production and reproduction, feeds and nutrition, genetic principles, practical aspects of breeding programs, and prospects for future genetic improvement	• Information on taxonomy, distribution, growth characteristics of *C. gariepinus* relative to other African catfish • Technical aspects of catfish production and reproduction in the context of African countries • Feeding and nutrient requirement of African catfish as a basis of the formulation of balanced diets • Principles for the design of a breeding program and essential pre-requisites for effective dissemination of improved fish to farmers • Practical aspects of an on-going breeding program of *C. gariepinus*, including control of reproduction, methods of individual identification, rearing and tagging • Potential application of molecular information and reproductive technologies in practical breeding programs
4	To identify future priorities for research and training in order to enhance local capacity in aquaculture and catfish production	• Establishment of the physical infrastructure needed to undertake selective breeding of catfish • Conducting regional training courses to address human resource needs in genetics and brood stock management • Genetic characterization and conservation of important populations of *C. gariepinus* • Initiation of genetic improvement programs in African catfish including the foundation of base populations, choice of breeding technology, implementation of the selection program • Development of public-private partnership (PPP) training programs to improve private sector hatchery capacity in brood stock and seed production • Strategies for effective dissemination of improved seed including a regional producers symposium
5	To develop a concept note as a basis for future proposal development	• A synthesized outline of the future project with clear objectives, justification and outputs, methodologies and activities, anticipated budgets and potential impacts (Annex F)

on the importance of setting up a genetic improvement program for African catfish in the region, and the need to establish close cooperation and a working network in the area of aquaculture as a whole. He also expressed that he had high expectations after this workshop, and that he hoped that the workshop recommendations would soon materialize.

On behalf of the participants, Mr. Seth Agyakwah expressed gratitude to the organizers of the meeting. He personally appreciated the workshop which gave him and the participants a good insight and a considerable amount of knowledge about various technical aspects of African catfish production. He thought that the workshop was a great opportunity to exchange experience and develop ideas for future breeding programs in African catfish. Mr. Seth Agyakwah also stressed the participants' interest in and need for training in the area of quantitative genetics applied to catfish improvement.

The meeting was officially concluded at 5:00 p.m., Friday, 9 November 2007.

COUNTRY CASE STUDY: CATFISH INDUSTRY IN CAMEROON

David Nguenga[1], Victor Pouomogne[1] and Randall E. Brummett[2]
[1] IRAD, BP 255, Foumban, Cameroon
[2] The WorldFish Center, BP 2008, Yaoundé, Cameroon

ABSTRACT

Despite the long history of fish farming in Cameroon (since 1948), large private farms remain scarce and production from small subsistence units is low and does not contribute significantly to national fishery production. Since the independence of Cameroon, development of the aquaculture sector has been largely driven by international donor support. Little attention has been paid by the government and there has been no master plan for aquaculture development with clear and achievable targets. However, Cameroon's poor rural populations rely on fish as their main source of animal protein. To satisfy the high demand for fish, Cameroon imported over 130,000 tonnes of frozen fish in 2006, which represents an important loss in currency. Government production statistics are unreliable. Total fish production from earthen ponds was estimated at 870 tonnes in 2006, of which *Clarias gariepinus* represented nearly 38 percent.

The responsibility for developing the aquaculture sector in Cameroon is vested in the Ministry of Livestock, Fisheries and Animal Industries (MINEPIA). Aquaculture research falls within the competence of the Ministry of Scientific Research and Innovation (MINRESI), more precisely in the Institute of Agricultural Research for Development (IRAD). There are 12 fish stations and 20 fish breeding centers under the MINEPIA, but most of them are now in a state of disrepair or abandonment. Within the IRAD, the Foumban Fish Culture and Fisheries Research Station with regional and international vocation has the responsibility to carry out research activities on aquaculture and inland fisheries throughout the country.

As the government stations failed to produce catfish seed on a regular basis, fish farmers have increasingly turned to private seed suppliers. Wild caught seed, especially *Clarias* species caught in the Nkam River Basin in the western and littoral provinces of Cameroon, are an important component to be taken into account regarding aquaculture development and the sustainable management of the aquatic ecosystem.

The unit of production is exclusively earthen ponds with the main cultured species (*Oreochromis niloticus, Clarias gariepinus* or *Cyprinus carpio*) either in mono- or polyculture. Semi-extensive production system is common, dominated by small-scale ponds. Indirect feeding through compost cribs loaded with available organic input (mainly grass and weeds) and kitchen refuse is the general practice. Average production is around 2,000 kg/ha/year. Farmers using balanced pellet diets registered up to 9,000-16,000 kg/ha/year.

The quantity of fish produced is usually very low compared to demand. In this respect, nearly all fish is sold at the pond side (farm gate) and there are no marketing problems.

The lack of high quality fingerlings and feeds, as well as the inefficiency of extension services has been identified as some of the factors retarding aquaculture development in Cameroon. The Cameroonian Strategic Framework for Sustainable Aquaculture Development (also known as the Limbe Declaration, 23-26 March 2004) has addressed these major constraints.

Cameroon has a long history of aquaculture. The first study carefully designed on the use of the African catfish *Clarias gariepinus* (= *Clarias lazera*) for aquaculture was started in 1974 at the National Fish Culture Center in Foumban, Cameroon, as part of a UNDP/FAO Fish Culture Development Project.

Since 1985, research activities related to freshwater aquaculture have been conducted at the Foumban Fish Culture and Fisheries Research Station. Most activities are oriented toward optimizing the artificial propagation of the main cultured catfish (*Clarias gariepinus* and *Heterobranchus longifilis*), as well as domesticating new catfish species suitable for aquaculture.

There is a general lack of knowledge on the genetic variability of the different strains of *C. gariepinus* farmed in different parts of Cameroon, this species being alien to the river basins in which it is cultured. Data on the reproductive biology and feeding habits of catfish species in the wild are also lacking. The policy environment is now supportive and Cameroon will become an important aquaculture producer in the near future.

INTRODUCTION

The aquaculture industry in Cameroon is essentially rural and its objectives are to increase fish supplies and provide supplementary and alternative employment, generate income, and improve the nutrition of subsistence farmers (Satia et al. 1988). However, fifty-nine years after the introduction of aquaculture in the country, it has failed to improve rural nutritional and income standards. Its contribution to national fishery production remains insignificant. Cameroon, although self-sufficient in most domains of agro-food, has defaulted on its provision of fish products. Fish continues to be the main source of protein for the Cameroonian populations, especially for the most underprivileged layers (Nguenga and Pouomogne 2006). The national production is essentially assured by the country's maritime, artisanal and industrial fishing and by continental fishing. The national needs increase annually in proportion with the population growth. The gap between demand and supply obliges Cameroon to import considerable quantities of frozen fish.

In 2005, nearly 49 percent of animal protein consumed in Cameroon, 17 kg per person annually, consisted of fish (Brummett 2007). Demand is high and continues to rise with imports passing 53,000 tonnes in 1997, 63,000 tonnes in 1998, and 78,000 tonnes in 1999. In 2002, Cameroon imported 182,000 tonnes of fish, representing 52 percent of domestic supplies, at a total cost of nearly US$90 million (FAOSTAT 2004). Fish prices remain stubbornly high at around US$3.50 per kg live weight on the wholesale market. Through a series of consultations facilitated by FAO (April 2003 and December 2004) and the WorldFish Center (April and November 2004), access to markets, availability of high quality technical backstopping and regular supply of fish fingerlings have been repeatedly identified as key constraints to aquaculture growth. According to the government, if these can be overcome, Cameroon has the biophysical potential (i.e. land, water and feed materials) to easily produce 20,000 tonnes of fish per annum through aquaculture, and increase the current production by more than a factor of twenty.

OVERVIEW OF THE NATIONAL AQUACULTURE SECTOR

HISTORICAL BACKGROUND

Fish farming started in Cameroon in 1948, and in 1952 the colonial administration (England in the West adjacent to Nigeria, and France in the Eastern Cameroon) built 22 aquaculture demonstration stations to strengthen the fisheries sector. By 1960, the number of private earthen fishponds exceeded 10,000. Soon after independence in 1960, the extension effort collapsed, and most ponds were abandoned. During the early 1970s a UNDP/FAO regional project increased the number of public aquaculture stations to 32. However, declining donor support and the transfer of aquaculture from the Forestry Department to the Livestock Department weakened the enthusiasm. From 1980, there was a revival in focussed donor support for aquaculture. The USAID developed common carp farming in the Western Highlands (1980-84), and Peace Corps Volunteers assisted until 1998; the IDRC provided support for integrated fish-cum-pig-and-chicken farming from 1986 to 1990; the Belgian cooperation agency (General Administration for Cooperation and Development, AGCD) provided support for catfish seed production at the Foumban Research Station from 1990 to 1994; the French cooperation agency provided support for participatory aquaculture development in the Yaoundé region from 1994 to 1997; recently, DFID (UK Department for International Development) supported a participatory aquaculture project within the forest benchmarks of Cameroon from 2000 to 2005 (WorldFish Center 2005), and currently the French Department for Foreign Affairs is supporting research in a partnership project in the seven southern provinces (La Recherche Agronomique au Cameroun, REPARAC) (Pouomogne and Mikolasek 2006).

Since independence, the development of the aquaculture sector in Cameroon was, therefore, largely driven by international donor support. Given the stop-start, top-down nature of support, the evolution of the sector until the mid-1990s has been erratic and serrated. In 1995, after evaluating past experiences, the Cameroon government promoted a more participatory approach such as those supported by the French Cooperation Agency and DFID projects. This has resulted in considerable changes in aquaculture practices, improved use of local knowledge and practical experience at the farm and village levels. In addition, the revision of legislation regulating freedom of associations (1992) and increases in fish prices related to the devaluation of the CFA franc in 1994 have created an environment favorable to sustainable aquaculture development (Pouomogne et al. 1998; Pouomogne 2006a). Population growth and the concomitant increase in the demand for animal protein have also contributed significantly to escalating fish prices. As a consequence, many abandoned ponds have recently been rehabilitated, although this has often been done without technical input from reliable specialized extension services. This positive trend is linked to the new market environment and facilitated by recent changes in policy.

PRODUCTION TRENDS

An analysis of available data from the National Agricultural Research and Extension Program (PNVRA), the WorldFish Center, the FAO Special Program for Food Security and the Department of Fisheries of the MINEPIA revealed that by the end of 2004 there were approximately 4,000 active farmers with 7,000 ponds (>50% new or rebuilt since 1995) with an average size of 350 m². Total fish production from earthen ponds was estimated at 600 tonnes, of which more than 90 percent was produced by small-scale farmers. Nile tilapia (*Oreochromis niloticus*) was the most commonly farmed species, followed by African catfish *Clarias gariepinus*. The most common practice is polyculture of Nile tilapia, with *Clarias gariepinus* where possible, or with other locally available species such as *Heterotis niloticus* (“kanga”), *Channa obscura* (“viper fish”), *Hemichromis fasciatus* (“panther fish”), common carp (*Cyprinus carpio*) or *Barbus* species (Pouomogne 2005b). The fingerlings of the other species listed above are obtained mostly from the wild. The progress of aquaculture production from 1990 to 2006 is shown in Table 1.

Table 1: **Aquaculture production (tonnes) in Cameroon (1990-2006)**

Species	1990	2000	2003	2004	2006
Nile tilapia	80	180	250	350	450
African catfish	6	120	180	230	330
Others	20	50	70	70	90
Total	106	350	500	650	870
Total pond surface (ha)	160	210	220	240	245
Observations	FAO 1997	Personal estimation, based on actual field records after PNVRA, WorldFish, FAO Cameroon and some specialized NGOs (CEPID, SEAPB); Pouomogne 2006b			personal estimation

INDUSTRY STRUCTURE

Responsibility for developing the aquaculture sector is vested in the Ministry of Livestock, Fisheries and Animal Industries (MINEPIA) through the Department of Fisheries (DIRPEC). Aquaculture research falls within the competence of the Ministry of Scientific Research and Innovation (MINRESI), more precisely in the Institute of Agricultural Research for Development (IRAD).

There are 12 fish stations and 20 fish breeding centers under MINEPIA (Table 2). Each station constitutes the nucleus of activities in a given area and a number of breeding centers are attached to it. The fish stations were designed with the primary objective of producing fingerlings to support the development and expansion of aquaculture. Of these government fish stations and breeding centers, a large number are now in a state of disrepair or abandonment.

According to Brummett (2007) in a recent case study reviewing fish seed supply in Cameroon, although these stations are largely dysfunctional, some of the more important of them possess considerable infrastructure and potential for contributing to aquaculture development, if either properly managed or transferred to the private sector. These include:

- Ku-Bome, 35 ponds, 5.9 ha
- Bamessing, 13 ponds, 1.5 ha
- Bambui-Nkwen, 22 ponds, 1.7 ha
- Foumban, 53 ponds, 3.5 ha
- Yaounde, 14 ponds, 2.0 ha
- Ngaoundere, 24 ponds, 4.0 ha
- Bertoua, 42 ponds, 12.0 ha
- Garoua-Boulai, 9 ponds, 4.2 ha

Table 2: Public breeding centers and fish culture stations under MINEPIA

Province	Division	Name of breeding center (C) or station (S)
Adamaoua	Vina	Ngaoundere (S)
	Mbere	Meiganga (C)
	Mayo Banyo	Banyo (C)
	Faro and Deo	Tignere (C)
Center	Mfoundi	Yaounde (S)
	Dja and Lobo	Sangmelima (C)
	Haute Sanaga	Nanga-Eboko (C)
	Lekie	Monatele (C)
	Mbam Inougou	Bafia (C)
	Nyong and Mfoumou	Akonolinga (C)
	Nyong and So'o	Mbalmayo (C)
East	Lom and Djerem	Bertoua (S)
	Kadei	Batouri (C)
	Haut-Nyong	Doume (C)
	Haut-Nyong	Abong-Mbang (C)
	Lom and Djerem	Betare-Oya (S)
	Lom and Djerem	Garoua-Boulai (C)
Far-North	Mayo Tsanaga	Mokolo (S)
Littoral	Moungo	Nkongsamba (S)
	Moungo	Melong
	Moungo	Loum
	Sanaga Maritime	Ndom
North-West	Ngo-Ketunja	Bamessing (S)
	Mezam	Bambui-Nkwen (S)
	Momo	Ku-Bome (S)
	Momo	Batibo (C)
West	Mifi	Bafoussam (S)
	Menoua	Dschang (C)
	Bamboutos	Mbouda (C)
	Nde	Bangangte (C)
	Noun	Foumban (S)
South	Mvila	Ebolowa (S)
	Dja and Lobo	Sangmelima (C)

Among the catfish species, *Clarias gariepinus, Clarias jaensis* and *Heterobranchus longifilis* appear to be farmed the most. *Clarias jaensis* seeds are collected from the wild as techniques for artificial reproduction are yet to be established.

As these government stations have failed to alleviate any of the main constraints on aquaculture, fish farmers have increasingly turned to other suppliers for information and fingerlings. Since the revision of the laws covering the formation of farmer groups was lifted in 1990, over 90 NGOs and Common Initiative Groups dealing with agriculture and rural development, including aquaculture, have sprung up. Many of these offer technical advice on aquaculture, and a few have attempted to operate small hatcheries to supply their members with seed. Unfortunately, the level of technology used by these groups is minimal, and none of the efforts to overcome the seed shortage have so far produced sustainable outcomes.

As a result of the failure of hatcheries to meet the demand for fingerlings, most farmers buy or trade amongst themselves, or buy fingerling from fishers.

The poor seed supply situation is exacerbated by a lack of fish growers. Without a sufficient number of growers to buy fingerlings over the course of a year, hatcheries cannot be profitable. On the other hand, if suitable fingerlings are not available when needed, producers cannot produce. Since 2002, the WorldFish Center, in conjunction with the Government of Cameroon and a local NGO called Service d'Études et d'Appui aux Populations à la Base (SEAPB), has focused attention on the linkage between markets, producers and hatcheries with the objective of developing practical strategies for private-sector hatcheries, grow-out and marketing that can allow smaller-scale producers to participate, and possibly lead to growth of fish farming in and around the urban markets of Central and Western Provinces. At present, three private catfish hatcheries engaged in this joint project are the main suppliers of high-quality fingerlings in the country (Table 3).

The total number of fingerlings traded is unknown, and government production statistics are unreliable because most fish are consumed in villages and do not reach urban markets where they might be counted. According to the WorldFish Center's project datasets, approximately 15 tonnes of fresh

Table 3: Private catfish hatcheries known to be operating in Cameroon as of November 2005

Farmer	Location	Species	Facilities	Status
Nkoua, Bruno	Nkoabang, Central Province	Catfish	Hatchery building + 7 ponds, 9,000 m^2	Active
Diogne, Michel	Batié, West Province	Catfish	Hatchery building + 6 ponds, 2,400 m^2	Active
Ndoumou, Antoine	Nkolmesseng, Central Province	Catfish	1 pond + 8 tanks, 2,500 m^2	Active
Wouanji, Jean	Bandjoun, West Province	Catfish	3 ponds, 900 m^2	Startup
Youdom, Bernard	Batié-Nsoh, West Province	Catfish	10 ponds, 5,000 m^2	Startup
Tamo, David	Bafoussam, West Province	Catfish	6 ponds, 1,200 m^2	Startup
Awoa, Lucien	Yemssoa, Central Province	Catfish	Hatchery building + 5 ponds, 3,200 m^2	Startup
Tabi, Abodo	Mbankomo, Central Province	Tilapia, catfish	Hatchery building + 19 ponds, 9,500 m^2	Dormant
Yene, Joseph	Nkoabang (Lada), Central Province	Catfish	12 ponds, 360 m^2	Periodic
Yong-Sulem, Steve	Mbankolo, Central Province	Catfish	23 ponds, 2,100 m^2	Periodic
Noupimbong, Maurice	Bapi, West Province	Catfish, tilapia	6 ponds, 700 m^2	Periodic
Oben, Benedicta	Buea, SW Province	Catfish	Hatchery building + 5 concrete tanks	Periodic
Ebanda, Jeanne	Mbandoum, Central Province	Tilapia	17 ponds, 7,000 m^2	Dormant

(From: Brummett 2007)

catfish were traded at the urban market of Yaoundé in 2004. To produce this amount of fish, 185,000 catfish fingerlings were stocked. If these values are extrapolated to the government estimates (2002) of 114 tonnes of catfish, the total number of fingerlings stocked was on the order of 1.4 million.

The collection of fingerlings from the wild for aquaculture appears to be on a smaller scale compared to fishing catfish for direct human consumption. In 2006, about 10 tonnes of catfish were harvested from flood ponds in the Nkam River Basin. Over 300,000 *Clarias jaensis* fingerlings were collected and distributed for aquaculture, along with almost 50,000 *Clarias gariepinus* (Pouomogne 2007).

In Cameroon, collecting catfish juveniles for culture-based aquaculture is specific to the Nkam River Basin. Surprisingly, within the hundreds of rivers of the same scale in which *Clarias* spp are fished, collection of juveniles remains a marginal activity.

The Foumban IRAD Specialized Station with regional and international vocation is responsible for carrying out research activities on aquaculture and inland fisheries throughout the national territory. Research facilities such as ponds (1 ha), a modern hatchery with a flow-through and a re-circulating water system (estimated capacity of fry production: 2 million annually), equipment and facilities are available and, in the near future, will enable the station to satisfy the demand of fish farmers in terms of seed of the various fish species cultured in Cameroon.

PRODUCTION SYSTEMS AND FARMING PRACTICES

Cameroon has a 475,000 km² surface area of which 63.5 percent, the so-called Big Southern Cameroon with favorable agro-ecologic features (namely year-round rainfall distribution), presents fair potential for earthen pond freshwater aquaculture. The unit of production is exclusively earthen ponds with the main cultured species (*Oreochromis niloticus, Clarias gariepinus* or *Cyprinus carpio*) either in mono- or polyculture.

Use of the semi-extensive production system is common, dominated by small-scale ponds. Indirect feeding through compost cribs loaded with available organic input (mainly grass and weeds) and kitchen refuse is the general practice. This is a consequence of the systematic impoverishment of rural people due to the macro-economic policies imposed by the World Bank and the International Monetary Fund (IMF) from the end of the 1980s. On average, the compost cribs comprise 10 percent of the pond surface area. The average production is around 2,000 kg/ha/yr. The most progressive farmers (about 15% of the total) are concentrated mainly around Yaoundé (the capital city). They use additional organic fertilizers (e.g., dry chicken droppings from commercial chicken farms) or compounded low cost pellets (presently available from the IRAD and the WorldFish Center's pilot feed manufacturing plants). The recent participatory approaches of the WorldFish Center and FAO have resulted in production levels of around 9,000 kg/ha/year. A group of wealthier farmers using pelletized balanced diets registered up to 16,000 kg/ha/year, but for poor human capital management reasons, the process is far from being sustainable.

MARKETING SYSTEMS

The quantity of fish produced is usually very low compared to demand. In this respect, nearly all fish are sold at the pond side (farm gate) and there are no marketing problems. For peri-urban farmers, connecting them with fresh fish retailers revealed that fish produced (namely tilapia, *Clarias* and *Heterotis*) from ponds near large cities could be sold at a higher market price than fish from other places. The chain of this rather luxurious produce is thus usually very short, i.e. from the producers to the consumers, with sometimes one intermediary retailer.

PROBLEMS, ISSUES AND CONSTRAINTS

Aquaculture has been practiced for more than 50 years in Cameroon, and not a single known self-sustaining aquaculture business can be inventoried in the country. The story of this activity parallels the history of the country: booming from 1950 (start) to 1960 (independence); decline until 1970 (more burning preoccupations for the new state) with the start of foreign multilateral donor assistance (UNDP/FAO); then, erratic and serrated evolution in relation to sporadic external funding until 1990, followed, to date, by a new collapse and a long period of failure for nearly all demonstration stations. It may be recalled that following the end of the 1980s crisis, the governing paradigm changed, putting a stop to the "state-does-all" attitude. Single private and common initiative groups were promoted, and more freedom was given to undertake them, but with higher taxation pressures. In aquaculture research and extension, participative or partnership approaches have been initiated. As a consequence, the net production has increased, following increased funding of partnership research, mainly by international donors.

Based on the process just described, the following guidelines may be recalled:

- In the context of Cameroon, aquaculture is a tough activity, actually more difficult to master and to gain profit than other activities in the agricultural sector.

- For sustainability, farmers need to gain money from it, and aquaculture should be considered as such and not continuously marginalized as a subsistence activity: good quality seed and feed, and capital to acquire basic materials are necessary to push the production above the minimum critical level.

- Partnership action research involving well trained and philosophically convinced researchers and technicians working with promising farmers as a team should be encouraged. In other words, only demand-driven research, conducted by persons humble enough and with a deep desire to learn and exchange with committed producers, and within an environment where many such producers can be found should be funded using the scarce money available.

- Special credit opportunities may then be made available to support the starting business. The government may, in addition, maintain reference stations to conserve basic genetic material and care for other high-cost equipment required to implement the business initiative and monitor its activities.

PAST AND CURRENT RESEARCH IN CATFISH

Fish farming started in Cameroon in 1948. The country has a long history of aquaculture research. It started in 1967 with the UNDP/FAO Regional Fish Culture Development Project covering four countries in Central Africa: Congo, Gabon, Central African Republic and Cameroon. However, most of the work undertaken has been of an empirical nature. The first study carefully designed was on the use of the African catfish, *Clarias gariepinus* (formerly called *Clarias lazera*). Aquaculture was started in 1974 at the National Fish Culture Center in Foumban, Cameroon, as part of a UNDP/FAO Fish Culture Development Project (Hogendoorn 1983). Field experiments on the controlled propagation of *C. gariepinus* were carried out. Reproduction could be induced in small ponds using desoxycorticosterone acetate (DOCA). In artificial reproduction experiments, ovulation was induced with acetone-dried carp pituitary glands. Sexual products were obtained by stripping the females and dissecting the males. Artificial fertilization, incubation and hatching were successfully carried out. Different methods of producing fingerlings in earthen ponds were compared. To optimize the artificial reproduction of *C. gariepinus* for aquaculture, experiments were carried out on short-term sperm conservation as well as hypophysation of the females and determination of the correct timing of stripping with respect to water temperature. The suitability of some common, natural and artificial feedstuffs for the rearing of fry of *C. gariepinus* was investigated. Experiments were also carried out to study the effect of different feeding levels and feeding frequencies on the growth and survival of *C. gariepinus* fingerlings. The effects of stocking density, pond size and mixed culture with *Oreochromis niloticus* under extensive field conditions were investigated. Experiments were also carried out to study the effects of body weight, temperature and feeding level in intensive tank culture.

Since 1985, research activities related to freshwater aquaculture have been conducted at the Foumban Fish Culture and Fisheries Research Station within IRAD. The activities in this domain have essentially been oriented toward the optimization of the techniques of induced reproduction of *Clarias gariepinus* and *Heterobranchus longifilis*, larval rearing in earthen ponds of *C. gariepinus* (Yong-Sulem et al. 2006a, b and c), valorization of agricultural by-products, and the production of these species in earthen ponds under different farming systems. The influence of seasonal changes on the oocyte diameter, responses to hormonal induction and hatching quality were investigated in *Heterobranchus longifilis* (Nguenga 1997). The effects of storage and incubation temperature on the viability of eggs, embryos and larvae were also studied (Nguenga et al. 2004). Although basic catfish reproduction technology has been well established, the larval rearing still poses serious problems due to high mortalities in ponds caused by inappropriate starter feeds, cannibalism and predation. Investigations are underway to solve these problems.

PRIORITY AREAS AND FUTURE DIRECTIONS

Cameroon has considerable potential for aquaculture development. The hydrographic network is dense and comprises several perennial streams and rivers. Within this vast array of aquatic resources reside at least 600 species of freshwater fish. However, only a small number of species are suitable for aquaculture, and few have actually been produced commercially (Brummett 2007). *Clarias gariepinus* is the most farmed catfish species in Cameroon. However, it appears that this species is alien to the river basins in which it is cultured, having been introduced by various aquaculture projects. Its native range in Cameroon encompasses the Benue River and Lake Chad. As a consequence, there is an urgent need for the genetic characterization of the various strains. Because knowledge of the biology of natural reproduction can be helpful in developing successful hatchery and nursery procedures, investigations should be carried out on the reproductive biology and feeding habits of potential catfish species suitable for aquaculture.

CONCLUSIONS AND PERSPECTIVES

Cameroon has the potential to become an important aquaculture producer. The climate and water are good (although soils and topography are less favorable), markets are excellent, human technical capacity is modest, but adequate, and basic infrastructure exists in the form of an active research program and a functioning training center.

In addition, the policy environment, although currently vague, is generally supportive. Three international agencies (WorldFish Center, the French Centre de Coopération Internationale en Recherche Agronomique pour le Développement and FAO) are currently active in Cameroon's aquaculture and are working closely with the government and each other to ensure that past mistakes are not repeated and best practices are put in place to ensure that future growth of the sector is sustainable.

Despite the general lack of money, the Government of Cameroon has repeatedly expressed its commitment to the development of aquaculture within the country, and the supply of high-quality fingerlings has been identified and clearly enunciated as the key constraint.

The new IRAD catfish fingerling and broodstock quality assurance program is a step in the right direction and is linked to private sector initiatives by the Strategic Framework for Aquaculture Development.

Cameroon is heading towards a resolution of its fingerling supply problem and the creation of a robust aquaculture sector.

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THE AFRICAN CATFISH *CLARIAS GARIEPINUS*: A PERSPECTIVE ON ITS ROLE AND POTENTIAL IN EGYPTIAN AQUACULTURE

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ABSTRACT

Egyptian aquaculture has grown rapidly over the past fifteen years and now provides an important component of national food supply. Production has increased from 35,000 tonnes in 1992 to 540,000 tonnes in 2005. This aquaculture production represents more than 60 percent of the national fisheries production in 2005, an increase from just 17 percent in 1992. The main increase has come from tilapia (*Oreochromis niloticus*) production, making Egypt the world's second largest producer of tilapia.

This paper analyses the conditions and implications of this spectacular growth and the most recent trends and challenges facing the sector's development and sustainability. In particular, it looks at farming systems, product range and species diversification potential with special reference to the African catfish (*Clarias gariepinus*). It places the industry in the context of the overall fish supply and demand in Egypt, bearing in mind the leading role of Egyptian aquaculture as a model for the whole of the African continent.

INTRODUCTION

Fish farming has an ancient history in Egypt, dating back to at least 2000 B.C. (as seen on the walls of the tomb of Thebaine). "Modern aquaculture", on the other hand, stagnated at a relatively low production level of around 55,000 tonnes per year until the 1990s. Over the last ten years, however, production has risen sharply to 540,000 tonnes in 2005, contributing over 60 percent of national fish production (GAFRD 2006). Fish farming has become an important component of the agricultural sector in Egypt and a significant source of animal protein. Production in Egypt makes up 78 percent of the total aquaculture production in the combined regions of the Near East and North Africa and sub-Saharan Africa (FAO 2006).

Looking at the demand side in Egypt, to maintain the current per capita fish consumption in Egypt at the same level of around 15 kg, a total of 200,000 tonnes of fish was imported in 2005 to fill the gap between fish supplies and demand for local consumption. Thus, with an inability of the capture fisheries sector to expand sustainability beyond the current harvest levels, the aquaculture industry at large, whether freshwater or marine aquaculture, is challenged to meet the growing demand for fish and shellfish. Keeping in mind the continuing growth of the population, it is expected that the existing gap between fish supply and demand will become wider, leading to a more pressing need for fish production from aquaculture with an expected demand volume of about 1.5 million tonnes by the year 2017. To achieve this growth and move beyond current production levels, the constraints currently faced by the sector will, therefore, need to be removed, and profit margins of farmers will need to be maintained. New species or technologies may become available and could be important over the longer term, but most of the growth and development is likely to occur through further development of existing sub-sectors.

Within the freshwater sector, and assuming the introduction of alien species remains well regulated, the most interesting species would probably be the African catfish (*Clarias gariepinus*), with established hatchery capability, good performance both in monoculture and even more so in polyculture with tilapia, and potential market development opportunities.

OVERVIEW OF COUNTRY PRODUCTION

Valued at some LE 3.5 billion at first sale, this aquaculture production represents more than 60 percent of the national fisheries production in 2005, an increase from just 17 percent in 1992 (Figure 1).

This growth in aquaculture production has been vital in supplying the needs of Egypt's growing population, and in helping to maintain stable prices in the face of diminishing wild catches and increasing competition for global supplies. As the "Food for Man", aquaculture will have to play an even more definitive role in meeting the dietary needs of an increasing population, while making up for the decline in natural marine resources.

PRODUCTION SYSTEMS

The main increase in aquaculture production has come from tilapia (*O. niloticus*), making Egypt the world's second largest tilapia producer. Tilapia (mainly *Oreochromis niloticus*), carps (mainly common carp) and mullets (Mugilidae) are the three main fish species contributing over 95 percent of total aquaculture production during the period from 1995 to 2005 (Figure 2). The remaining 5 percent of fish production from aquaculture came from other species such as catfish, sea bass and sea bream, and actually very little from penaeid shrimp.

The tilapia share in Egyptian aquaculture production has risen to more than 217,000 tonnes in 2005 (40% of the total aquaculture production) (GAFRD 2006) compared to 9,679 tonnes in 1994 (16% of total aquaculture production). On the other hand, farm-raised catfish represented just less than 2 percent of the total aquaculture production in 2005, as indicated in the official GAFRD statistics (Figure 2).

It is worth mentioning that this is the first time that African catfish have a whole digit representation in the Egyptian aquaculture production. Over 28 percent of the total African catfish production was derived from aquaculture in 2005 as compared to less than 2 percent in 2004. The basic information on the annual production of the African catfish from different sources and its trends and dynamics as well as the average annual wholesale prices over the period from 1995 to 2005 are shown in Table 1.

Within the freshwater sector, and assuming that the introduction of alien species remains well regulated, the most interesting species would probably be the African catfish (*Clarias gariepinus*), with established hatchery capability, good performance in tilapia polyculture, and potential market development opportunities. As can be seen

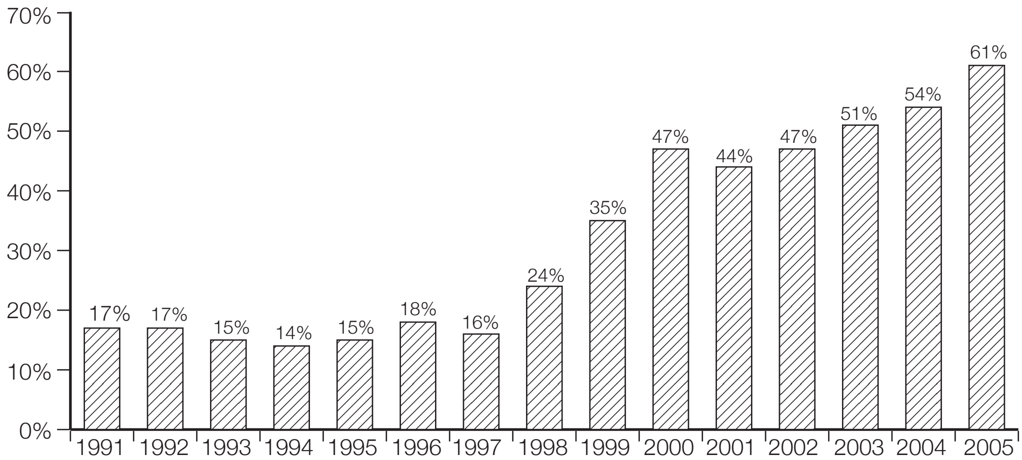

Figure 1: Aquaculture production as percentage of total fish production in Egypt from 1991 to 2005 (Source: GAFRD statistics 2006)

from the previous table, fish farming has not been a major source for the African catfish produced in Egypt except for 2005 when considerable amounts of farmed catfish were recorded (more than 10,000 tonnes) for the first time since 1996. Prior to the year 2005, most of the catfish production came from the country's natural fisheries such as the River Nile and northern and internal lakes (Figure 3).

A number of factors have resulted in the substantial increase of the farm-raised catfish production in Egypt including, first of all, the availability of its fingerlings. The market demand for the species has been on the rise and its sale price has been increasing as shown in Table 1.

PRODUCTION SYSTEMS

Seven separate sub-sectors can be defined, of which five represent the core of production, one is traditional and rather marginal, and another is emergent. Two further sub-sectors may emerge, but have not been developed. Most reporting sources use broadly similar definitions, based primarily on the physical form of production

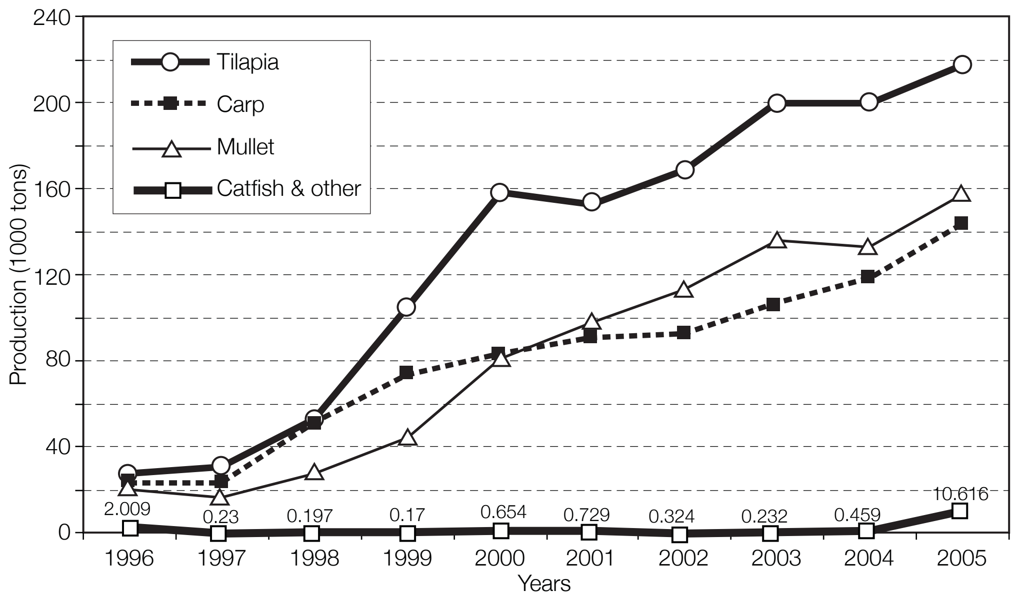

Figure 2: Important species produced in fish farms from 1996 to 2005 (Source: GAFRD 2006)

Table 1: Total annual production (tonnes) of the African catfish *Clarias gariepinus* and average annual wholesale price (LE/kg) from 1995 to 2005

	Production year										
Source	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Lake Manzala	3844	2114	5206	2814	5893	11585	10759	8943	13548	9646	7272
Lake Burulus	2270	3429	3205	2940	2315	2459	2204	1909	2067	2172	2875
Lake Edku	479	528	592	687	652	501	938	937	373	56	103
Lake Mariut	738	900	1094	1135	1653	2360	2398	1954	1928	1933	2094
Rayan depression	11	15	19	25	47	115	21	26	35	34	55
River Nile and tributaries	10755	11310	12317	11613	10951	14486	23215	25439	25158	12992	13422
Aquaculture		2009	23	197	17	654	729	324	232	459	10180
Total catfish production (tonnes)	18097	20305	22456	19411	21528	32160	40264	39532	43341	27292	36000
Avg price (LE/kg)		3.25	3.50	3.75	3.75	4.22	4.16	4.1	4.38	4.84	5.30

and input intensity, in turn correlating in general with specific areas and species groups. The primary definitions of sectors and their potential, with the most important sectors shaded, are given in Table 2.

For tilapia, most of the production is concentrated in the Nile delta, close to the Northern Lakes, with some in Fayoum. In 2004[1], the total production in the delta was 191,578 tonnes, approximately 96.3 percent of the national total, while Fayoum accounted for 3.3 percent, farms south of Fayoum 0.3 percent, and farms near Cairo around 0.1 percent. In the delta area, Kafr-El Sheikh governorate produced the most tilapia with 88,079 tonnes, followed by Damietta and Sharkia, with 36,319 tonnes and 30,186 tonnes, respectively.

In 2004, most tilapia production derived from earthen ponds; in private farms 155,541 feddan[2] produced 173,164 tonnes. Government ponds covered 13,728 feddan, producing 3,699 tonnes of tilapia. Tilapia production in earthen ponds represented 89 percent of the total tilapia production, the remaining 11 percent being from intensive production in cages and tanks. Kafr-El Sheikh produced the most tilapia using earthen ponds, whereas Damietta produced the most using intensive cages. All governorates using intensive methods produced tilapia in cages, although Beheira and El-Fayoum also used tanks. By 2007, only Beheira continued intensive farming with cages and tanks, El Fayoum with tanks and Kafr-El Sheikh with cages.

Since 2004, intensive tilapia production has been reduced as the government has removed most cages following concerns about environmental impacts and navigational obstruction. By December 2006, there were 2,702 cages[3] remaining out of the original 12,495 cages in 2004. These are in the Rosetta Nile branch after the last dam gate between the river and the sea, where water is brackish and is outside the authority of the Ministry of Irrigation.

African catfish production is likely to increase in importance, particularly in polyculture with tilapia, taking into consideration the emerging situation and challenges facing the aquaculture sector such as the fluctuating/declining sale price for tilapia, while catfish prices are on the rise (Figure 4) and emerging legislation and regulations banning the use of sex reversed tilapia fry in aquaculture.

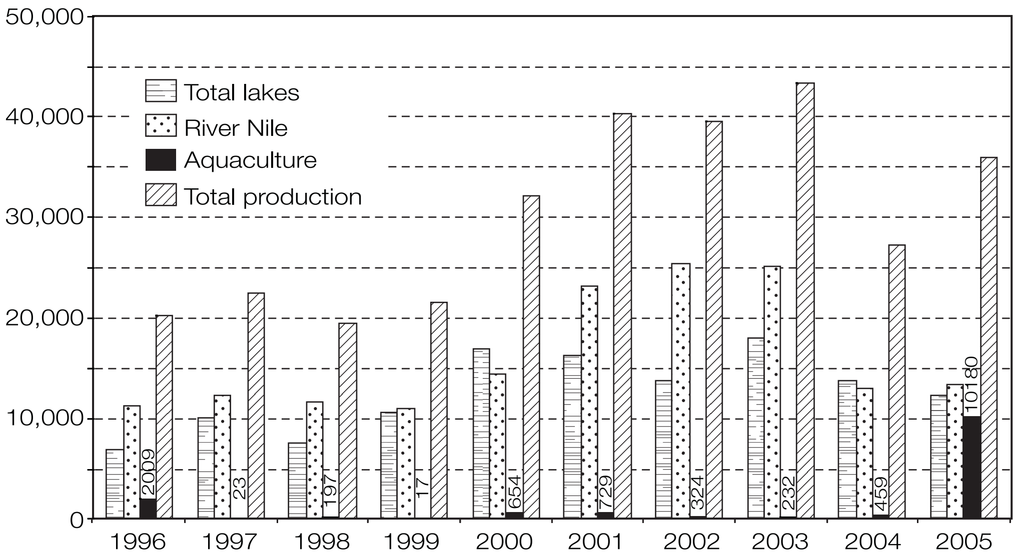

Figure 3: Categorized production of African catfish (tonnes) from different sources from 1996 to 2005

1 Data obtained from the General Authority for Fisheries Resources Development (GAFRD) statistics
2 1 feddan = 4,200 m^2 – conversions are given throughout the text although spreadsheets use SI related units.
3 Total number of cages was 2,702, of which 2,300 were in Beheira and 402 in Kafr-El Sheikh.

Table 2: Sub-sector definitions, output (2005) and potential (most important areas shaded)

Farming system/ category	Key features/ locations	Species produced	Productivity	Estimated output (tonnes)	Key constraints
Extensive/unfertilized					
E1 Fisheries-based aquaculture	Fish seed introduced into open water bodies	Various species, also grass carp*	Very low, unmeasured	Un-recorded	Management
E2 Integrated (Rice-fish)	Some carp seed still stocked, little data*	Mainly common carp, some tilapia	8-40 kg/feddan	17,000 t	Seed; possibly water
E3 Pond (extensive)	Traditional stocked/self-seeded areas	Tilapia, mullet, African catfish some carps	200-1,000 kg/feddan	68,400 t	Water
Semi-intensive/supplementary fed					
S1 Pond (semi-intensive)	More developed, mainly tilapia based, some moving to I1	Tilapia and some mullet	1,500–4,000 kg/feddan	273,500 t	Water, cost-efficient feeds, quality seed, markets
Intensive/mainly fed					
I1 Pond (intensive)	More modern smaller units, often better managed	Tilapia	4,500–6,000 kg/feddan	113,900 t	Feed, water, markets also seed, disease
Highly intensive/ completely fed					
H1 Integrated (intensive tank system)	Developed in new agricultural zones	Tilapia	15-25 kg/m^3	2,250 t	Water, disease, also market, feed, seed
H2 Cage culture – Nile branches and irrigation canals	In January 2007 cage numbers were 20% of those in 2005	Tilapia and silver carp (now main species)	10-30 kg/m^3	57,400 t	Sites/water access, markets, feed, disease, seed
H3 Cage culture – coastal/marine	Future potential	Various higher value marine species	10-30 kg/m^3	NA	Sites, seed, also feed, disease
H4 Intensive recycle system	Future potential value species	Various higher	40-100 kg/m^3	NA	Markets, energy costs

* Free distribution of various carp species at different times; this has influenced uptake and output; tilapia seed is also sometimes used.

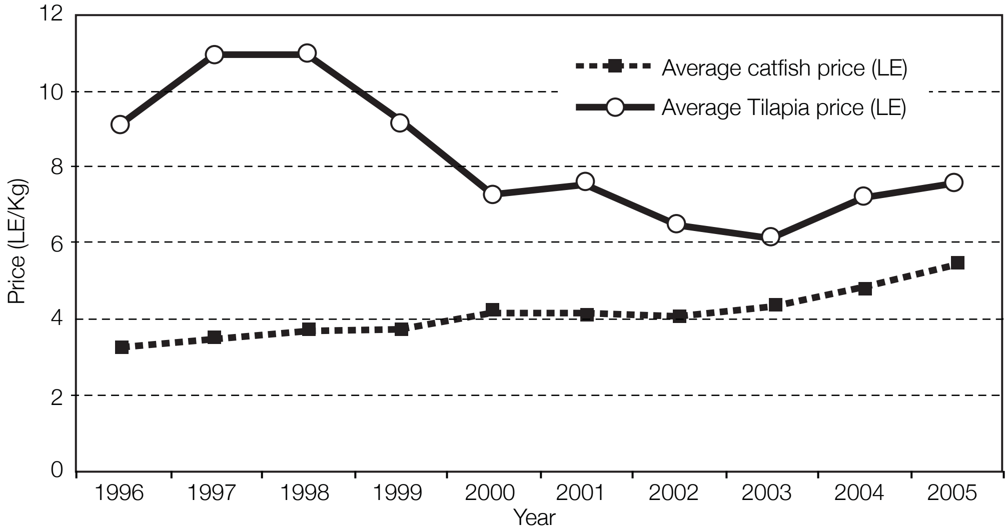

Figure 4: Annual average sale price (LE/kg) for African catfish (*Clarias gariepinus*) and Nile tilapia (*Oreochromis niloticus*) during the period from 1996 to 2005

Polyculture of Nile tilapia with African catfish has been shown to be technically viable if certain factors are considered, such as adjusting the species ratio and the stocking density, as well as providing high quality fish feed according to the proper amount and time interval.

MARKETING SYSTEMS

There is little detailed information so far on the marketing structure, preferences and substitutability of catfish. It appears that traditional local and city market structures still represent the bulk of trading, mainly operating through traditional wholesalers. However, contract buying from some fish farms or producer groups is also being practiced, which is consistent with aquaculture-linked market changes seen in other countries. According to Feidi (2004) a large quantity of fish is transported to the main national market of El-Obour for auction and the fish are then distributed to all parts of Greater Cairo. Catfish seem to enjoy a better market in the rural areas of the country and an even higher demand in the southern parts of the country (Upper Egypt) where they are sold live. The market price for a kilogram of fresh catfish currently ranges from LE 5.5 to 6.5 ($1.0 to $1.3), while smoked dried ones are higher.

PAST AND CURRENT RESEARCH ON CATFISH

FEED AND NUTRITION

The evolution of feed and pond fertilization has followed a typical path, from initial use of agricultural by-products such as wheat bran, rice bran and trash fish, offered in its original form without any processing, together with cattle or chicken manure for pond fertilization. Most fish farmers in Egypt apply fertilizers and feeds, and the bulk of farm production uses supplementary or complete feeding. With positive returns to intensification using these inputs, crumbled cattle feed was then used, although its levels of fiber and of growth inhibitors such as gossypol (from cotton seed hulls) were too high. Greater attention was directed to suitable formulations (Osman and Sadek 2004), following which a modern fish feed sector has developed. Compressed (sinking) pellets, with 25 percent crude protein content, comprise the bulk of fish feeds produced. Extrusion technology for making floating pellets was introduced in the late 1990s. The market for extruded feeds is growing (El-Sayed 2007) with a range of different formulations of fish feed available for different fish species, including catfish, ranging from specialized larval feeds to fingerlings and grow-out feeds.

The overall use of feeds has been variously reported, from estimates of only 100,000 tonnes of feed supporting a production of 450,000 tonnes of fish, to more recent and probably more supportable estimates of 250,000 tonnes of fish feed production. This accounts for about 10 percent of the total animal feed sector (El-Sayed 2007). According to El-Sayed (2007), most feeds are now produced commercially; farm-made feeds are rarely used and only by small-scale fish farmers. They usually mix farm-made feeds by using various energy sources such as wheat bran, rice bran or ground corn, with protein sources (mainly local fishmeal or trash fish) at a 3:1 ratio. Ingredients and inclusion levels vary locally depending on availability and cost.

A number of studies have been conducted to test different feed formulations targeting the replacement of imported fishmeal with locally available animal protein sources, in particular poultry by-product meal and locally produced fishmeal both as a separate source and as a mixture of both in the formulation. Results strongly demonstrated good potential for using a mixture of the two replacing sources for the best growth performance of African catfish reared in earthen ponds (Safwat and El-Naggar 2004; and El-Naggar and Yehia 2006).

MANAGEMENT: PRODUCTION CYCLE FROM BREEDING, NURSING, REARING TO GROWING OUT

Across Africa there is a substantial and growing demand for African catfish as a preferred food fish. Farming of this species is, however, constrained by the limited availability of fingerlings and the dependence on hormonal injections for spawning.

To address this latter constraint, research on non-hormonal technologies has been carried out by the WorldFish Center since 2000. This led in 2002 to the identification of a methodology that could be used by farmers. Further refinements to this method have taken place during 2003–2004.

In parallel with refining the technology, the Center engaged in training activities for technicians and farmers' associations on the use of the technology in Egypt and Malawi. Training was provided either as a component of the training courses organized at Abbassa or as a special training activity for groups of farmers and technicians from Egyptian universities and research institutions, as well as for technicians from the region.

As a result of the well-established hatchery technology for pond spawning and open pond nursery systems developed for the species (El-Naggar et al. 2002, and 2006), fingerling availability is no longer an issue for the species. In 2005, farmers in Egypt began to produce and market fingerlings using this WorldFish-developed technology and demand for fingerlings from other farmers is growing rapidly. Sales of catfish have more than doubled in the last two years on some farms, and specialized catfish hatcheries are now being developed by private sector partners to increase production further.

Polyculture of Nile tilapia with African catfish has been shown to be technically viable if certain factors are considered, such as adjusting the species ratio, stocking density and high quality fish feed with the proper quantity and time interval (El-Naggar 2007).

BREEDING AND GENETICS

The WorldFish Center has started a program on pedigree selection of *Clarias gariepinus* in 2005 to improve the performance and quality of cultured catfish.

PRIORITY AREAS AND LIKELY FUTURE DIRECTIONS

Developing greater efficiency and output through strategic gains in efficiency brought about by selected application of science and technology — these would apply over the medium- and long-term, but although market forces and technical innovation will be major enabling factors, the sector's potential cannot be fully realized without a sufficiently supportive policy background and associated legal instruments and other implementation measures.

These are some points to be considered for future directions:

- Protocols for hatchery production of the African catfish should be set out carefully, recognizing the realities and costs of doing so;
- To develop and disseminate genetically improved seed on a reliable and continued basis, an effective system will require at least one dedicated breeding center in which genetic improvement is carried out and a range of seed multiplication centers (i.e. hatcheries) that make the genetically improved seed available to farmers;
- Efficient polycultures, optimizing water and feed inputs, production/value outputs and environmental impacts, will become an increasingly valuable approach to combining better water and feeding management while optimizing output;
- Feeds will increasingly need to be tailored for different production phases and seasons, and for the extent of partial or complete feeding. Likewise, feeds for other species and/or for polyculture mixes should be further developed;
- Feeding performance is at the heart of cost-effective production in most aquaculture systems. With, for example, a 60 percent contribution of feed costs to typical production costs, a 10 percent drop in feed cost per tonne of output will as a single factor deliver a 6 percent drop in the break even sales price. Depending on demand elasticity, this alone could support market expansion of 3-5 percent, while maintaining profitability;

- Losses due to disease, adverse weather and environmental conditions, and other disruptions should be reduced through better management protocols and established emergency responses; and
- Value-added formats need to be considered and developed as new markets open for smoked fish, either locally or for re-exporting as value-added products to neighboring Arab states, and consequently strengthen the sector's role and potential for expansion. Sometimes this may simply be improved convenience, with improved information and availability, and not requiring sophisticated technical responses.

CONCLUSION

In conclusion, one can say that the Egyptian aquaculture sector as a whole is one of the most important and promising sectors for providing a good protein source for the people of Egypt, thus playing an essential role in improving livelihoods through food security as well as creating new employment opportunities and fighting poverty. This role is expected to become even more prominent and, at the same time, there will be more challenges to keep up with its current advancement levels in light of the growing demand as a result of the country's increasing population and the limitations of available resources. African catfish does have the potential to provide a sizeable contribution to the required fish production from aquaculture, provided that the current constraints are tackled and overcome. If done appropriately, this will help the development process of the entire aquaculture sector, not just catfish.

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STATUS OF CATFISH FARMING AND RESEARCH IN GHANA

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ABSTRACT

A review of the catfish farming industry and research in Ghana was conducted to generate baseline information on current farming practices, production volumes, marketing systems and industry structure, as well as the status of research activities on the clariid catfishes *Clarias gariepinus* and *Heterobranchus* species. The information is expected to contribute to national planning and development of the aquaculture industry for enhanced fish production, improved livelihood opportunities and assured food security. The culture production of catfish is estimated at 10 percent of the total national aquaculture production that is currently 950 tonnes. The clariid catfish are generally cultured in semi-intensive systems in polyculture with tilapia (mainly *O. niloticus*) and in some cases with the bony tongue *Heterotis niloticus* by small- and medium-scale fish farmers. The number of catfish hatcheries is very limited, with an estimated production capacity of 4 million fingerlings annually. There is no breeding center or program for the development of improved catfish strains. Research on the clariid catfish has mainly focused on the biology, reproduction and husbandry (e.g. nutrition, culture systems and hatchery management). A huge local market exists for the catfish, mainly as smoked fish, while opportunities abound for both fresh and smoked exports to the European markets. Major constraints hampering the development of the catfish industry are outlined, and priority areas and likely future directions for accelerated growth in the aquaculture industry are suggested.

INTRODUCTION

Fish is the principal animal protein source for Ghanaians. Over the years, fish has contributed about 70 percent of animal protein intake. Presently, the national fisheries production from both the capture and culture sectors is estimated at 391,694 tonnes, out of which aquaculture contributed 0.3 percent, valued at US$2.251 million (FAO 2006). National fish demand stands at 648,694 tonnes, hence a shortfall of 257,000 tonnes (FAO 2006).

Production of fish from commercial and artisanal fisheries has continued to decline over the last two decades due to several factors including over-exploitation, pollution, destruction of fish habitats, destructive fishing practices and loss of foreign fishing grounds (Balarin 1988; Danquah et al. 1999; Ofori-Danson et al. 2001, 2002; Braimah 2003), while per capita fish consumption continues to increase from 22 kg/caput/year in 1997 to 28 kg/caput/year in 2002 (Owusu et al. 2001; FAO 2006). The role of aquaculture to bridge the gap between current demand and national production has long been recognized worldwide, as it has in Ghana (FAO 2004; Attipoe 2006).

Fish farming in Ghana follows two basic systems: monoculture and polyculture. The tilapias (mainly *Oreochromis niloticus*) and the catfish (*Clarias gariepinus, Heterobranchus longifilis* and *Heterobranchus isopterus*) are the main species cultured in dugouts, pens, earthen ponds and cages (Owusu-Frimpong et al. 1993; Attipoe 2006).

The potential of catfish in aquaculture to increase and sustain national fish production has long been recognized in Africa and, for that matter, in Ghana (De Kimpe and Micha 1974; Hogendoorn 1979; Hecht 1982; Danquah et al. 2006). However, its culture is still on a limited scale in Ghana. The ability of catfish, especially the clariid catfish *Clarias* and *Heterobranchus*, to live in water with extremely low dissolved oxygen and high carbon dioxide content makes them excellent fish for culture. Catfish can easily be cultured at high density and give very high production per unit area. *Clarias* and *Heterobranchus* catfish are highly esteemed as a delicacy. They are commonly cultured as a "police fish" to control unwanted reproduction in tilapia ponds (Owusu-Frimpong 2006).

This paper reviews the state of catfish production in Ghana. It highlights past and current research efforts and examines constraints hampering the development of the industry. Priority areas and likely future directions are suggested for the development of the catfish industry in Ghana.

OVERVIEW OF COUNTRY PRODUCTION OF CATFISH

HISTORICAL BACKGROUND OF AQUACULTURE

Fish farming started in Ghana in the early 1950s with the construction of fishponds, dams and reservoirs by the former Department of Fisheries (now called the Ministry of Fisheries) in the Northern and Upper regions of the country. These were to serve as hatcheries to provide fish seed to support the culture-based reservoir fishery development program of the colonial administration and as a way of supplementing the national demand for fish and increasing livelihood opportunities (Balarin 1988).

After independence in 1957, the national government adopted a policy to develop fish ponds within all irrigation schemes in the country, thus state-owned irrigation facilities were developed as far as was technically possible by converting 5 percent of the schemes into fish ponds (Owusu et al. 2001). A campaign by the government of Ghana in the early 1970s to raise more fish as a "backyard farming activity" led to the construction of several earthen fishponds in both urban and rural areas of the country. However, most of them were abandoned due to a number of factors including – lack of technical know-how, inadequate extension services, lack of fish seed to stock ponds, inadequate formulated fish feed, and lack of capital to expand farms (Owusu et al. 2001).

Since 1993, interest in fish culture has revived and aquaculture is now widely practiced throughout the country with a concentration in three of the ten administrative regions of the country (Abban 2005). The majority of fish farmers are small-scale operators using extensive fish farming practices. Fish are produced mainly in earthen ponds. Over the last four years, cage culture of tilapia has been established in the Volta Lake by a number of private investors. The cage farmers have adopted intensive farming practices by feeding their fish with balanced diets that they either prepare themselves or buy from the two commercial feed companies selling compounded diets in the country.

CATFISH PRODUCTION

Fish production from aquaculture in 2004 was estimated at 950 tonnes by the Directorate of Fisheries. Although production has not been separated by species, it is known that tilapia (mainly *Oreochromis niloticus*) is the dominant species and constitutes nearly 88 percent of the total aquaculture production (FAO 2006). Catfish is the second most important cultured species. Its culture constitutes about 10 percent of the total national aquaculture production with the remaining 2 percent consisting of other species such as *Heterotis niloticus*. Catfish production has generally fluctuated between 95 and 200 tonnes per year within the last decade, with highest and lowest productions in 1996 and 2003, respectively (Figure 1).

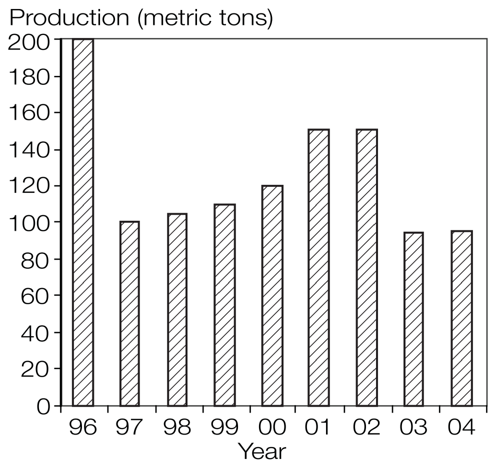

Figure 1: Estimated production level of catfish in Ghana from 1996 to 2004 (Source: Ministry of Fisheries, Ghana; estimates from FAO 2006)

Accurate production figures on catfish at regional levels are not available due to poor record keeping by the majority of farmers and an inadequate number of government extension officers who lack the needed resources to collect reliable data in rural areas where most of the production is undertaken. Estimated figures from fish farmers are, therefore, lower than what is actually produced. Major concentrations of fish farms are located in the Ashanti, Western and Brong-Ahafo regions. In the Central, Eastern and Volta regions farms are less concentrated (Figure 2). Culture based fisheries involving polyculture of several species of tilapia (predominantly *O. niloticus, Sarotherodon galilaeus* and *Tilapia zillii*), catfish, *Hemichromis fasciatus, Heterotis niloticus* are predominant in dugouts that are generally located in the three northern regions, namely Upper East, Upper West and Northern regions (Figure 2).

Production figures of catfish by species are also not available. They were, however, bulked together from production of the two main species *C. gariepinus* and *H. longifilis*. Both species are usually available on most farms and are cultured either in the same pond or in separate ponds.

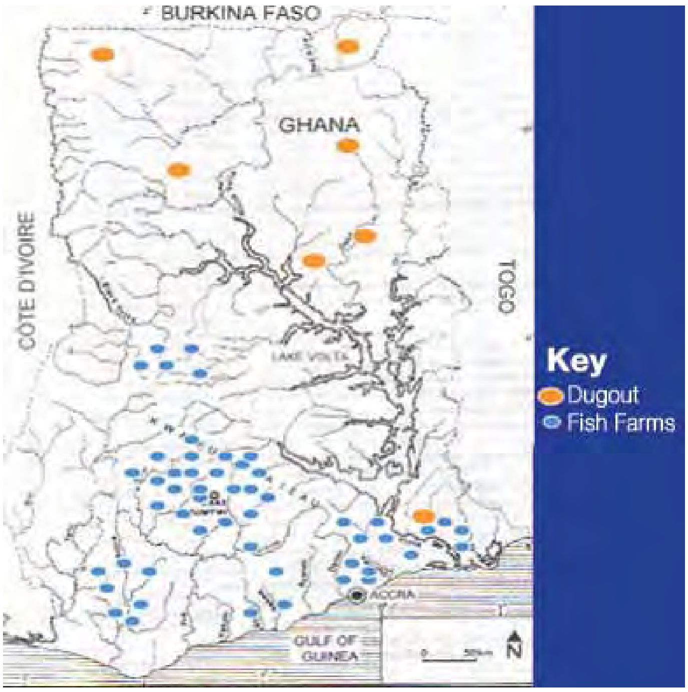

Figure 2: Distribution of major fish farms and dugouts in Ghana

INDUSTRY STRUCTURE

The Ministry of Fisheries is the lead agency vested with the administrative control of aquaculture. It is also the main institution responsible for planning and development in the aquaculture sub-sector. The CSIR-Water Research Institute is the main institution mandated to carry out aquaculture research in the country.

Currently, there are no breeding centers or nucleus stations dedicated solely to the development and production of improved catfish breeds. However, a national breeding center for the development and production of fast-growing *O. niloticus* is established at the CSIR-Water Research Institute's Aquaculture Research and Development Center (ARDEC) at Akosombo. The Center, in collaboration with the WorldFish Center, has developed a fast-growing *O. niloticus* strain (the Akosombo strain), which currently grows about 20 percent faster than the wild populations. More than 40 percent of fish farmers currently use the Akosombo strain in polyculture with clariid catfish.

HATCHERY OPERATIONS AND SEED PRODUCTION

The number of catfish hatcheries in the country is very limited and range from small- to medium-scale. Presently, there are three main public and a few private owned hatcheries (Table 1). Prior to 2003, about 90 percent of the farmers in the catfish industry relied heavily on fingerlings collected from the wild to stock their ponds. This situation resulted in gross under-stocking of the ponds, as the number of fingerlings supplied was inadequate. The range in size of the fingerlings to stock the ponds was very wide; this led to skewed fish sizes at harvest, low survival rates and generally reduced income earnings.

An attempt was made by the government of Ghana to address the shortfall in seed supply to farmers by sponsoring a number of private fish farmers on a study tour to Uganda and Thailand to get first-hand information on modern catfish production systems currently in operation. The outcome of the tour has been a tremendous improvement in hatchery operation and grow-out management of the catfish industry. Currently about 50 percent of the seed requirement is obtained from hatcheries. The capacity for seed production from existing hatcheries is estimated at 4 million fingerlings per annum (Table 1).

Generally, breeders for hatcheries are collected from various streams and rivers. The practice of brood stock collection is done throughout the year, but is optimized during rainy seasons when breeders are in a good condition for spawning. The average number of breeders used per hatchery annually ranges from 30 to 40 females and from 60 to 80 males.

Over the last two years, some of the hatcheries have produced their own brood stock by selecting jumpers (shooters) from grow-out ponds. Occasionally, some male breeders are collected from the wild to replenish the breeding stock. The purpose of replenishing the male breeding stock is to replace depleted numbers because males are generally sacrificed for milt and their pituitary gland during the artificial spawning process. This practice indirectly contributes to improving the genetic diversity and fry fitness, and reduces inbreeding.

Fry production in hatcheries generally follows the techniques of induced spawning. Pituitary gland suspension is prepared and injected into berried females from 10 to 15 hours prior to stripping. Milt from males is mixed with the eggs and activated in clean water, after which they are spread on mosquito mesh nets and incubated in concrete tanks with a flow-through water system from 18 to 30 hours. The period of hatching depends on the water temperature. Larvae are fed exclusively on either *Artemia* nauplii or *Moina* after yolk re-absorption for 4 days. Thereafter, the catfish larvae are fed on a combination of *Artemia* nauplii or *Moina*, and formulated diet (CP 40%) for 4 days. Twelve days after hatching, the fry are exclusively fed on formulated diets (locally prepared by farmers, or produced industrially, e.g. GAFCO and AGRICARE, or imported from Israel, i.e. Dizengoff). Fry are transferred into shaded outdoor concrete tanks or earthen ponds for nursing. Prior to their transfer, green water is generated by applying poultry manure. Fry are sorted every two weeks to reduce the incidence of cannibalism. Jumpers are separated from average growers using improvised graders. The survival rate of fry during the first two weeks in a private hatchery ranges between 40 percent and 60 percent, while survival during the nursing period, which lasts from 4 to 8 weeks ranges from 20 percent to 30 percent.

Table 1: Production scale of major clariid catfish hatcheries in Ghana

Category	Institution / region	Scale of operation (x '000) fingerling/month
State owned	ARDEC (Eastern)	Medium (50 – 100)
	MoFi (Ashanti)	Small (< 50)
	KNUST (Ashanti)	Small (< 50)
Private commercial farmers	Kumah (Ashanti)	Medium (> 50 - 100)
	Boanda (Ashanti)	Small (< 50)
	Kpemli (Western)	Medium (> 50 - 100)

Note: MoFi = Ministry of Fisheries.

PRODUCTION SYSTEM

A survey carried out in 2003 by the Directorate of Fisheries which covered 77 out of 110 administrative districts in Ghana, identified a total of 709 small-scale fish farmers who operated 1,380 ponds with a total area of 112.28 hectares. Production systems used to rear catfish in Ghana vary from extensive to semi-intensive, with the latter accounting for about 60 percent of the total production. Some farmers rely wholly on the natural productivity of their ponds and occasionally throw left-over food into them, while others use single agro-industrial by-products, such as maize bran, wheat bran, rice bran, or groundnut bran to feed the fish. About 20 percent of the fish farmers, practicing the semi-intensive system of production, feed their fish with high protein diets purchased from commercial feed manufacturing companies operating in the country. Tanks and smaller earthen ponds are used as nursery receptacles to grow the juveniles to sizes suitable for stocking grow-out ponds.

MARKETING SYSTEMS

Catfish fingerlings are sold live at the farm gate as seed to fish farmers for stocking grow-out ponds. Current demand for catfish seed is very high throughout the year. This has resulted in the seed being sold at exorbitant prices. A 10 g catfish fingerling sells for 20 GHp[1] (US$ 0.21). Table-size fish is either sold fresh at the farm gate or smoked and sold later. Intermediaries, usually women, may also buy the fish in bulk from the farms, smoke and retail them in major market centers. Data on quantities that are sold as fresh or smoked fish are not available. However, it is estimated that about 70 percent of the cultured catfish is smoked. Fresh catfish is put on ice if it has to be transported from the farm gate to the market center in order to be sold fresh. Fresh catfish (mean weight 500 g) sells at between GHC 2.50 and 3.50 (US$2.70–3.80) at the farm gate. Some fish farmers' associations at Kadjebi and Tarkwa are jointly operating a deep freezer in which they store fish, including catfish, for sale to the public. This prevents intermediaries from buying the fish at a cheap price. In addition, smoked catfish are occasionally exported to Nigeria and the United Kingdom.

FEED AND NUTRITION

Approximately 90 percent of the fish farmers who feed their fish prepare their own feed from agro-industrial by-products, such as maize bran, wheat bran, rice bran, wheat eyelets, groundnut bran, copra cake, soya bean and fish meal. Since 2005, one local private commercial feed company called GAFCO has been selling sinking pellet fish feed to farmers. Another local private company, AGRICARE Ltd., also started production of sinking pellet fish feed for farmers in October 2007. A third company, Dizengoff Ghana Ltd., imports floating extruded diet from Raanan Fish Feed Ltd. in Israel. The crude protein levels of the imported fish feed range from 30 percent to 40 percent and are meant for both tilapia and catfish. This feed is in 20 kg polythene packs and is sold at GHC 0.90/kg (US$1.00/kg). The imported diets are very expensive and prices are beyond the reach of most farmers.

PROBLEMS, ISSUES OR CONSTRAINTS

The problems and constraints associated with aquaculture development in Ghana are principally related to three main issues: inputs, institutions and production (Abban et al. 2006).

INPUT ISSUES

ABSENCE OF FISH SEED

There is an acute shortage of fish seed in Ghana due to the absence of an adequate number of hatcheries in the country. This makes it difficult for most farmers to plan their production. Culture facilities are, therefore, underutilized and programmed production is disrupted leading to marketing problems. *Clarias* seed from the hatcheries are not certified. Owing to the scarcity, fish farmers rush and buy whatever is produced without due regard to the quality of the seed. Another problem is the location of the hatcheries in relation to the grow-out ponds. The grow-out ponds are located several kilometers from the hatchery centers; the transport of fingerlings to stock the ponds is very stressful and leads to a high mortality rate. This problem needs to be solved by setting up more public and private hatcheries close to grow-out facilities where modern state-of-the-art technology is applied to ensure the availability of high quality fish seed. Selective breeding methods that have been applied to improve the growth rate of *O. niloticus* through a collaborative research program between the Worldfish Center and the government of Ghana at Akosombo could be applied to catfish. This would protect genetic diversity, reduce inbreeding and improve the quality of the fish seed.

[1] The unit of currency in Ghana is the cedi (GHC or ¢) which is divided into 100 pesewas GHp).

LACK OF GOOD QUALITY FISH FEED

As stated above, only three brands of fish feed are currently sold on the Ghanaian market. Two of these are sinking diets that do not float. The brand imported from Raanan Ltd. in Israel is extruded and floats. However, it is very expensive and beyond the reach of the majority of farmers. It would be necessary for the government to support the local commercial feed manufacturers with credit lines to modernize their production equipment and add pellet extruder lines to their feed manufacturing plants. Further research should be accelerated on feed formulations using local agro-industrial by-products. A public-private partnership would improve production, reduce operational costs and enhance fish yields.

LACK OF FINANCIAL RESOURCES

Aquaculture is an expensive venture that requires the support of financial institutions. The Agriculture Development Bank (ADB) was set up by the government to support agricultural enterprises (including aquaculture). However, this did not materialize as aquaculture was viewed as a high-risk area due to the fact that some customers who accessed loans failed to pay back. Most farmers are, therefore, finding it difficult to access funds to improve their business. It would be necessary for the government to revise its policy on funding aquaculture enterprises and set up special funds with low interest rates to support the aquaculture sector.

INSTITUTIONAL ISSUES

EXTENSION

Ghana lacks an effective extension system to support a vibrant aquaculture development program. The number of trained extension personnel is grossly inadequate. A high proportion of the existing extension officers lack the knowledge and tools required to effectively transfer state-of-the-art technology to fish farmers. The policy of establishing a Unified Extension System adopted in the mid-1990s has negatively affected aquaculture development in the country. Most extension officers do not know what to do when faced with practical problems from fish farmers. With a substantive Ministry of Fisheries set up in 2005, it was expected that full-time aquaculture extension officers would be trained to effectively support the growing aquaculture industry.

RESEARCH, EDUCATION AND TRAINING

The research institutions and universities mandated to carry out research on aquaculture have not been adequately resourced to effectively carry out their duties over the years. Most of the funding has been provided by international donor agencies that sometimes pursue a program that may not be of a priority for the national research agenda. Some critical areas therefore lack research support. The public, private and donor agencies should work together to support a nationally determined research agenda for sustainable aquaculture development. There is also the need to develop an appropriate and structured educational program to train the human resources required to support the aquaculture sector.

PARTNERSHIPS

Public sector institutional linkages (i.e. research-private; government-private, private-private) are weak. National, regional and district fish farmers' associations are unable to positively influence government policy on aquaculture. There is, therefore, the need to strengthen fish farmers' associations and to provide training on relevant areas to enable them to operate effectively for the sustained growth of the industry in Ghana.

PAST AND CURRENT RESEARCH ON CATFISH

Research work on catfish species in Ghana was initiated during the late 1980s. The main institutions that pioneered catfish research during this period were the CSIR-Water Research Institute's Aquaculture Research and Development Center (ARDEC) based at Akosombo, and the Kwame Nkrumah University of Science and Technology (KNUST) located in Kumasi. Research activities on catfish have generally been focused on aspects related to biology, reproduction and husbandry (nutrition, culture systems and hatchery management).

Unlike the extensive breeding and genetic improvement research program conducted on the Nile tilapia, *O. niloticus*, resulting in an improved strain (namely the Akosombo strain) and increased production, virtually no such research has been conducted on the catfish. However, the Department of Fisheries conducted trials on the production of Heteroclarias through hybridization of *Clarias gariepinus* and *Heterobranchus longifilis*. Heteroclarias was observed to grow faster than the pure species, but was unable to reproduce naturally in ponds (Kumah, personal com.). Further trials on production and culture evaluation of Heteroclarias were discontinued due to ecological concerns related to biodiversity conservation.

CATFISH RESEARCH AT CSIR-WATER RESEARCH INSTITUTE (CSIR-WRI)

Clarias gariepinus and *Heterobranchus longifilis* have been the two main species of catfish under investigation at the CSIR-WRI (formerly the Institute of Aquatic Biology – IAB). Under a protocol of agreement signed between the International Development Research Centre (IDRC) of Ottawa, Canada and the government of Ghana, a study on 'Development of Improved Culture Systems for Increased Pond Production' was initiated in 1989. This work aimed at solving some of the problems associated with the reproduction and husbandry of catfish at the larval and grow-out stages (Owusu-Frimpong et al. 1990). Under this project, an outdoor hatchery was set up for the artificial reproduction of catfish. Initial spawning trials focused on: the application of different types of hormones to induce spawning; factors affecting incubation, hatchability and survival of fertilized eggs in stagnant and flow-through water systems; and the growth and survival of fry at the nursery and juvenile stages in tanks and in earthen ponds.

These initial research efforts were followed in the 1990s with on-station and on-farm studies aimed at improving survival at the juvenile and grow-out stages, and development of a reliable protocol for producing juvenile catfish at the rural level. Between 2003 and 2006, research was mainly conducted at the Aquaculture Research and Development Center (ARDEC) of the CSIR-WRI. It was sponsored by the World Bank through the Agricultural Sub-sector Capacity Building Project (AgSSIP). Under this project, activities undertaken aimed at improving the production of catfish seed, comparing yields from monoculture and polyculture systems, and controlling over-reproduction in tilapia populations using varying sizes and ratios of catfish. The results from these research efforts are summarized in Table 2a.

CATFISH RESEARCH AT THE UNIVERSITIES

Catfish research work at the Kwame Nkrumah University of Science and Technology (KNUST) was mainly conducted on *Heterobranchus isopterus*. The main areas of research were varied and related to the biology of the species. Most of the studies were conducted between 1991 and 2003. The following were some of the areas of investigation: catfish genetics (induction of triploidy in catfish), factors affecting the viability of storing sperm (germplasm); and catfish nutrition, such as investigating dietary protein and carbohydrate requirements of larvae, fry and juveniles, and examination of organoleptic properties and quality of the flesh of catfish. A summary of research conducted at KNUST in Ghana is shown in Table 2b.

PRIORITY AREAS AND LIKELY FUTURE DIRECTIONS

Aquaculture has the potential to contribute significantly to the economy of Ghana by providing improved livelihood opportunities and as a source of income to people involved in various sectors of the industry. This potential could be enhanced through

Table 2a: Major research activities on clariid catfish species (*Clarias gariepinus* and *Heterobranchus longifilis*) at the CSIR-Water Research Institute between 1990 and 2006

Year	Areas of research	Major results	Project/ reference
1990–1994	Development of capacity to reproduce catfish (*Clarias*) artificially – hypophysation,using various types of pituitary hormone	50% success in hatching experiments resulting in hatchability of 2% to 20%. Out of the study,fry to fingerling stage (mean wt. 0.6 g) achieved 22% survival. Low survival attributed to cannibalism, as well as frog and invertebrate predation	IAB / IDRC 1, 2 and 3
	Evaluation of *Clarias* and *O. niloticus* production in polyculture and monoculture systems	Production in polyculture system higher than in monoculture system	IAB / IDRC 3
	On-station and on-farm experiments to determine appropriate stocking densities and ratios of *C. gariepinus* and *Parachanna obscura* (Family: Channidae) both fishes used as "police fish", in controlling overpopulation of *O. niloticus* in polyculture system	*C. gariepinus* found to be less effective than *P. obscura* in controlling overpopulation of *O. niloticus*. Also the size and yield of *O. niloticus* better with *P. obscura* than with *C. gariepinus*	IAB / IDRC 4
	Development of on-farm incubation systems for production of catfish fry	*C. gariepinus* seed successfully produced in farm ponds using improvised incubators and root hairs of natural aquatic macrophytes, e.g. *Pistia* sp	IAB / IDRC 5
2002–2006	Development of *Clarias* and *Heterobranchus* fish seed for optimal growth and survival	Survival rates of catfish seed in earthen ponds higher (37.7% to 76.4%) than in concrete tanks (0.8% to 10.4%) at stocking densities of 90 fish/m^2. Mean weights of fry 0.182 g to 1.725 g at 30 to 42 days	AgSSIP / CSIR-WRI Annual Report 2004
	Development of procedures and techniques to optimize hatchery production of *C. gariepinus* and *H. longifilis*.	Protocol for production of catfish fingerlings by fish farmers for improved survival developed	National Agricultural Research Systems, Ghana 2006
	Determination of appropriate stocking combinations for efficient utilization of natural and supplemented feed in monoculture and polyculture systems	Higher growth performance obtained for all species in polyculture than in monoculture Higher yield obtained in polyculture than in monoculture	AgSSIP Project Report; Danquah et al. 2006
	Comparison of growth of *Clarias* and *Heterobranchus* in monoculture and polyculture systems in earthen ponds	Growth performance of *C. gariepinus* better than *H. longifilis* in both polyculture and monoculture systems	AgSSIP Project Report; Danquah et al. 2006

Table 2b: Research activities at KNUST on *Heterobranchus isopterus* from 1991 to 2003

Year	Areas of Research	Reference
1991	Induction of triploidy in catfish (*Heterobranchus isopterus*) by temperature shock treatment	Tsike 1991
	Performance of catfish (*H. isopterus*) fry fed on three types of feed	Bint 1991
	Organoleptic properties of traditionally smoked and chorkor smoked catfish (*H. isopterus*)	Oyih 1991
1992	Dietary protein requirement of the African catfish (*H. isopterus*) fingerlings	Agbobli Jnr. 1992
	Effects of compounded diets containing different carbohydrate protein ratios on growth and survival of the African catfish (*H. isopterus*)	Frempong 1992
1994	Growth of *H. isopterus* fed on diet containing plant protein at three different levels	Kwesie 1994; Owusu-Boateng 1994
2001	Assessment of growth and survival of *H. isopterus* fry	Wadie 2001
2002–2003	Factors affecting the mobility, viability and short-term storage of spermatozoa of *H. isopterus*	Amoo 2002 Asubonteng 2003

increased production of the African catfish *Clarias gariepinus*, which is second in order of importance of fish species cultured in Ghana. To achieve this, it is recommended that the following measures should be taken:

- Genetic characterization and documentation of the local strains of Clarias gariepinus in Ghana;
- Evaluation of the performance of the local strains in a number of production systems;
- Establishment of a breeding and selection program to improve the growth rate of the species;
- Establishment of nucleus centers and regional hatcheries for distribution of high quality catfish brood stock and fingerlings to farmers;
- Development of high quality feed that will sustain the aquaculture industry and make it viable;
- Training of various levels of human resources to sustain the industry. This should include researchers, extension officers and fish farmers;
- Strengthening of fish farmers' associations at local, district, regional and national levels for sustained economic growth; and
- Provision of sustainable credit facilities to farmers to initiate and/or expand aquaculture operations.

CONCLUSION

There is a very high potential for aquaculture production in Ghana to rapidly expand through the culture of the African catfish *Clarias gariepinus*. The climate and geographical conditions, especially in the southern portions of the country, favor increased production. The government of Ghana has taken several positive measures to support and accelerate the growth of aquaculture through the implementation of various strategies that have been outlined in the strategic framework for aquaculture development in the country. With careful planning and cooperation from all players within the sector, aquaculture would be able to contribute its quota to uplift the economy through the alleviation of poverty and provision of assured food security.

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CATFISH RESEARCH, PRODUCTION AND MARKETING IN KENYA

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ABSTRACT

This paper reviews the history of aquaculture research and development in Kenya with reference to the African catfish (*Clarias gariepinus*). The authors discuss the status of farmed catfish production in Kenya and market trends, as well as past and present research efforts. Increased demand for food and bait for the Nile perch fishery in excess of 18 million fingerlings per annum has led to increased interest and investment in catfish farming in Kenya. The main constraints to catfish farming are expensive feeds and lack of sufficient quality fish seed. To address these constraints, the government of Kenya recently initiated a catfish selective breeding program. Funding for at least ten generations will be required for maximal gain and success of the program. This paper outlines recommendations for future directions for the development and continuity of the catfish industry in Kenya.

INTRODUCTION

Catfish species of the genus *Clarias* originate in Africa and the Middle East (Teugels 1984). The *Clarias* species reported in East Africa, i.e. *Clarias gariepinus, Clarias liocephalus* (=carsonii), *Clarias werneri* and *Clarias alluaudi* (Greenwood 1966; Teugels 1984; CLOFFA 1986), inhabit wetlands, lakes and their affluent rivers. Of the catfish found in Kenya, the African catfish (*C. gariepinus*) is the most popular and relished for food. Apart from food, *C. gariepinus* fingerlings are used as baitfish for the Nile perch fishery in Lake Victoria because they are able to endure extreme conditions and can wriggle on a hook for over a week. The high growth rate of *C. gariepinus*, its ability to feed on a variety of organisms (Greenwood 1966), coupled with its ability to tolerate low oxygen, high concentrations of ammonia (NH_3) and nitrite (NO_2) in ponds and cages recommend it to aquaculture. *C. gariepinus* can be raised in high densities resulting in high yields of up to 16 tonnes per hectare per year [t/ha/yr] (Okechi 2004).

Aquaculture research and development efforts in Kenya have long concentrated on Nile tilapia (*Oreochromis niloticus*). However, local demand for the African catfish has led to increased production from fish farms in several African countries. A good example is Nigeria, where clariids including *C. gariepinus* have overtaken tilapia as the major culture species (FAO 2006). This indicates considerable potential for development of the catfish industry in other African countries like Kenya.

The aim of the present paper is to review the status of farmed catfish production (with emphasis on *C. gariepinus*) in Kenya and market trends, as well as the present research efforts and to recommend an appropriate research focus for further development of the industry in the country. To put the present status of catfish production in context, we present a short history of aquaculture and the status of production in Kenya.

BACKGROUND TO AQUACULTURE GROWTH IN KENYA

Fish farming in Kenya started in the early 1900s when colonialists stocked trout in rivers between 1910 and 1921 for sport fishing (Okemwa and Getabu 1996). From the early 1920s, static water pond culture was introduced, beginning with tilapiines and followed by common carp and catfish. In 1948, the colonial government established the Sagana and Kiganjo fish culture farms for the production of seed of warm- and cold-water species, respectively. The establishment of these stations sparked an interest in rural fish farming. It is thought that actual nationwide fish farming started around this time (Balarin 1985). The "eat more fish campaign" by the Fisheries Department in the 1960s led to the rapid spread of rural pond fish farming to other parts of the country. It is estimated that by the early 1970s, the Nyanza and Western provinces alone had over 30,000 fishponds (Zonneveld 1983). Most of the fishponds were small and many were abandoned soon after (Kagai 1975). Mariculture was introduced in the late 1970s with the establishment of the Ngomeni Prawn Farm pilot project. Despite the long history, aquaculture production has oscillated between 500-1,200 tonnes in the last few decades, far below capture fisheries (Figure 1). At present, the number of fish farmers is estimated at around 7,500-8,000 with over 10,000 ponds. Although aquaculture is yet to become commercial in Kenya (Fisheries Department 2003), strong interest by the private sector is increasing the prospects for commercialization of aquaculture activities.

Present indications are that production from capture fisheries is stagnating. Nevertheless, aquaculture still has to compete with capture fisheries for its market share.

CATFISH PRODUCTION

Aquaculture accounts for 0.6 percent of total fish production in Kenya, inland capture fisheries accounts for 95.4 percent and marine capture fisheries 4 percent. However, in the last few years, trade in catfish fingerlings as Nile perch bait has been on the rise. Polyculture of catfish and tilapia represents 15 percent of all culture production in Kenya, tilapia monoculture represents over 75 percent, trout takes about 5 percent and the remaining 5 percent consists of catfish monoculture (Ngugi and Manyala 2000). Aquaculture production data, especially species-specific data, are not reliable due to poor record keeping occasioned by partial harvesting and a lack of weighing balances. Therefore, the present data might be greatly underestimated and do not reflect actual production.

Catfish farming has started to gain momentum due to the high demand for Nile perch long-line fishing bait. In an effort to develop catfish as bait and a food fish, several government hatcheries and farms are involved in catfish production in the country. Nevertheless, individual farmers, motivated by financial benefits, are encouraged and are beginning to take up this role as well. Catfish is popular as a food fish in areas that are not predominantly fish eating, due to the high flesh to bone ratio. This indicates potential for carrying out catfish farming in areas outside the Lake Victoria basin.

AQUACULTURE PRODUCTION SYSTEMS

The majority of catfish producers in Kenya employ earthen ponds and concrete tanks. Recirculation systems are used to incubate the eggs to ensure that sufficient water flows into the egg incubation trays and aquaria. In the early stages prior to stocking in ponds, catfish are usually nursed in tanks. However, a few farmers grow-out their catfish to fingerling size in tanks. At least one farm, the Baobab Farm in Mombasa, engages in intensive grow-out of *C. gariepinus* and other species, such as tilapia and carps, in cages, tanks and raceways, as well as in ponds.

EXTENSION SERVICES

A multiplicity of government agencies carries out extension work to promote fish farming in Kenya. The Fisheries Department, Kenya Marine and Fisheries Research Institute (KMFRI), Moi University, Lake Basin Development Authority (LBDA), Coast Development Authority, and Maseno University are the key extension service providers. Apart from extension services, some of these agencies also conduct research and train farmers and extension technicians. The government also promotes fish marketing by providing marketing infrastructure. It also provides sources of seed and brood stock and organizes farmer field days for awareness creation and capacity building.

BREEDING, MULTIPLICATION CENTERS AND HATCHERIES

Several government agencies produce catfish seed and brood stock. Sagana Fish Farm of the Fisheries Department, Sangoro and Kegati Aquaculture Research and Development Center of the Kenya Marine and Fisheries Research Institute (KMFRI), Moi University Fish Farm and Kibos Fish Farm of the Lake Basin Development Authority (LBDA) are some of the centers that can host breeding programs. Since 2006, two of these centers, namely the Sangoro and Kegati Aquaculture Stations, have been running catfish and tilapia breeding programs with funding from the government of Kenya. These breeding programs target fast growth and survival of *C. gariepinus* and Nile tilapia.

Besides breeding centers, the government has over 20 hatcheries or multiplication centers scattered across the country. These include LBDA's five fry production centers in the Lake Basin at Yala, Alupe, Chwele, Borabu and Rongo. The Fisheries Department has several fry production centers, although only a few of these are operational. The Fisheries Department's operational multiplication centers include the Wakhungu Fish Farm and demonstration ponds at Murang'a, Kisii, Kisumu, Lutonyi, Yala and Nyamira. The average capacity for fingerling production at these hatcheries is approximately 140,000 fingerlings per year (Ngugi and Manyala 2000). This is equal to two million fingerlings annually from the government centers. Rehabilitation of these hatcheries could lead to much higher production of fingerlings.

MARKETING SYSTEMS AND CHALLENGES

MARKETING SYSTEMS

The catfish industry and marketing structure is shown in Figure 2. Fingerlings are sold live as baitfish or seed for stocking. They may be sold at the farm gate directly by the farmer or by middlemen to other fish farmers. Nile perch fishers buy them at fish landing beaches. Table-size fish are sold live at the farm gate or at market outlets. At

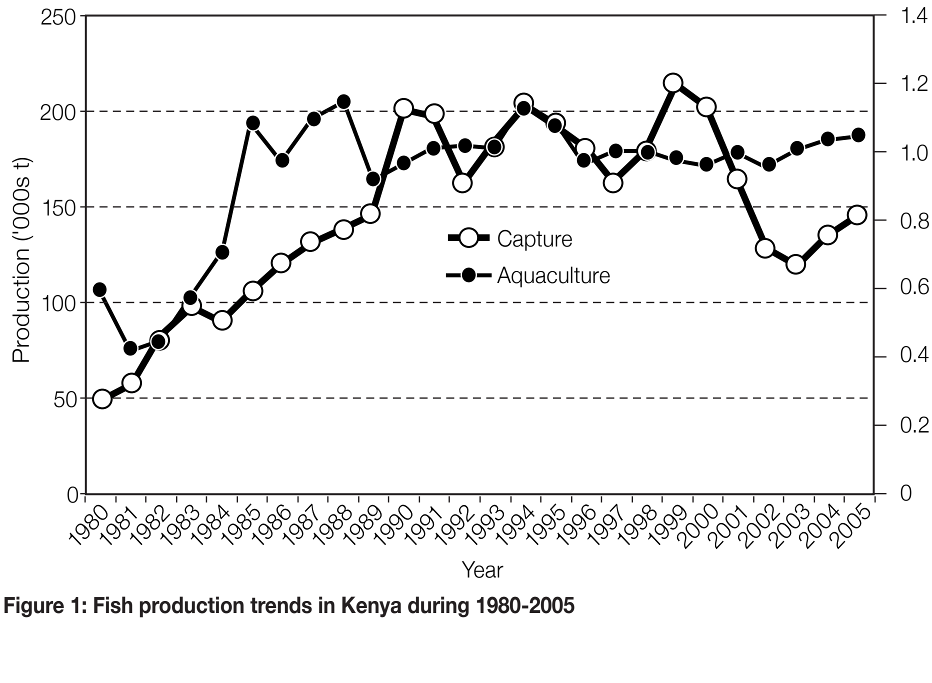

Figure 1: Fish production trends in Kenya during 1980-2005

the market, catfish are sold as whole fish, in pieces, or semi-processed (i.e. dried, smoked, fried or filleted). Because of the dwindling capture fisheries, demand for catfish products exceeds supply, offering great market potential. Prices of table-size catfish are still good for catfish farmers. A piece of catfish weighing 500 g retails for around Kshs. 100-150 ($1.50-2.50).

A recent survey in the Lake Victoria Basin indicated an overall demand of up to 50,000 catfish fingerlings per day as Nile perch bait, which equates to an annual demand exceeding 18 million fingerlings (Macharia et al. 2005). At the prevailing prices of Kshs 5 – 8 (or $0.07 – 0.10) per bait, this represents an industry worth Kshs. 97 million ($1.4 million). Over two million hooks are used daily in the Kenyan portion of Lake Victoria (Fisheries Dept. 2006) indicating a much higher shortfall in the supply of catfish fingerlings. Acquisition of fingerlings from the wild may deplete wild stocks because only a limited portion of the required catfish fingerlings originates from farms. Increased production of fingerlings from aquaculture could assist in conserving the wild stocks.

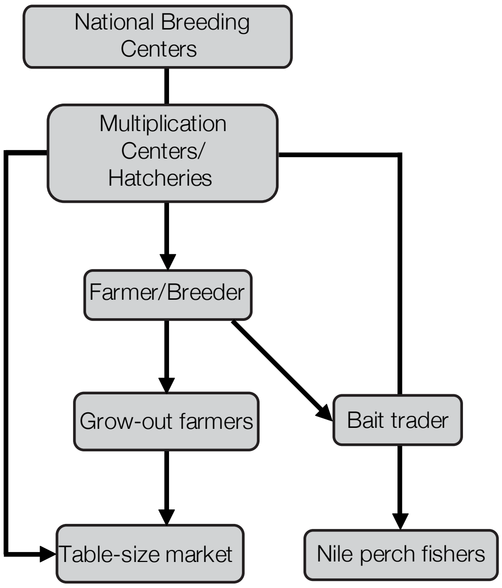

Figure 2: Catfish industry structure in Kenya

MARKETING CHALLENGES

Without clear information on market dynamics, investors may get into marketing problems. Upcoming catfish farms in Kenya need either to diversify or develop production strategies that correspond to the dynamism of marketing systems. This is because the level of demand for fingerlings in Kenya varies with each season and farmers should be aware of this seasonality to avoid overproduction. For example, the volume of fingerlings sold at the Kibos Fry Production Center from 1994 to 1998 peaked with the rainy seasons, i.e. March–May and August–October (Figure 3). This is the time when farmers require seed for stocking.

Currently, there are no functioning public-private production ventures in the country. However, partnerships in which private farms offer their facilities to research institutes and universities for joint research ventures are becoming common. This may be a precursor to the establishment of meaningful public-private collaborative research.

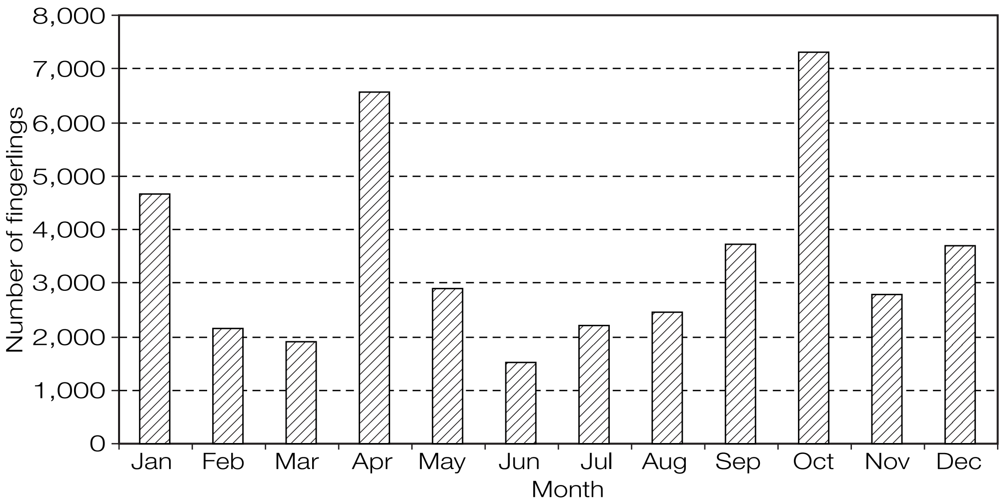

Figure 3: Volume and seasonality of catfish fingerlings sold at LBDA Kibos Fry Production Center

PAST AND CURRENT RESEARCH ON CATFISH

Despite the slow growth of catfish farming in Kenya, various research studies on catfish have been conducted.

RESEARCH ON BIOLOGY AND ECOLOGY

Various authors have described the distribution, habitat preference, ecology and biology of the African catfish (*Clarias gariepinus* Burchell). Viveen et al. (1977), Greenwood (1966) and Corbet (1960) reported that in Lake Victoria, *C. gariepinus* migrates upstream during the rainy seasons to breed, but Rinne and Wanjala (1982) indicated the existence of lake spawning populations. Greenwood (1966), Lung'ayia (1994) and Lowe McConnell (1975) described the feeding habits of *C. gariepinus* in Kenyan lakes and rivers.

SELECTIVE BREEDING AND GENETICS

In 2006, the government of Kenya approved funding for a three-year project called Selective Fish Breeding for Quality Seed to Enhance Aquaculture Production in Kenya. The aim of the project was to provide high yielding and quality seed of *C. gariepinus* and *O. niloticus* to farmers. The project started in mid-2006 with collection of brood stock from four different populations in the Lake Victoria region. Strain evaluation and growth studies of pure strains and crossbreeds of the different populations are ongoing at the KMFRI Sangoro Aquaculture Research Station. It was the expressed hope of the government of Kenya that donors and other partners would augment its efforts in carrying out the breeding programs for continuity.

MOLECULAR GENETICS

A comprehensive study on the phylogeny of *C. gariepinus* populations in Kenya has been done. The genetic structure at the ND5 and ND6 loci of mitochondrial DNA using RFLP–PCR indicated three phylogenetic groups occurring between the Western Rift, Lake Baringo, the Indian Ocean and Rufiji River (Giddelo et al. 2002). The study by Giddelo et al. (2002) indicated considerable variation in different populations from the East African region. Work by Teugels (1984) suggested a significant morphometric separation between the Nile and the Lake Victoria specimens of *C. gariepinus*.

No research has been done in Kenya on chromosome manipulation, polyploidy, gynogenesis, androgenesis, sex reversal, transgenic or genomics of *C. gariepinus*.

FEED AND NUTRITION

High quality commercial formulated catfish feeds are not available in the Kenyan market. Nutritional studies have concentrated on the use of inexpensive locally available feed ingredients for catfish due to the high cost of fishmeal. The freshwater shrimp (*Caridina nilotica*), blood meal, fish remains, rice bran, maize bran or wheat bran are used, depending on the region. The use of Omena, *Rastrineobola argentea*, is generally avoided because it also serves as human food. Christensen (1981) studied genetic aspects of nutrition and concluded that males grow faster than females, implying an advantage in rearing all male *C. gariepinus*.

FISH SURVIVAL, DISEASES AND PARASITES

In the culture of *C. gariepinus* under local Kenyan conditions, survival during incubation and from hatching to fingerling size is critical. Rasowo et al. (2007) evaluated the effects of formaldehyde, sodium chloride, potassium permanganate and hydrogen peroxide treatments on the hatching success of *C. gariepinus* eggs. Based on safety concerns, ease of availability and cost, Rasowo et al. (2007) recommended a 1,000 ppm sodium chloride treatment of catfish eggs for routine use by rural fish farmers to improve catfish egg hatchability. No work has been done to increase survival at the most critical stage: from hatching to fingerling. Survival to fingerling stage in unprotected ponds typically ranges from 0.6 to 21 fry/m^2 (Obuya et al. 1995). A survival rate of 25 percent or from 1 to 5 grams to fingerling size is considered good (ACRSP 2006).

Although not a major problem, parasite infestation may become common with intensification of catfish farming. Until recently, no work had been done on catfish parasites in Kenya. Fioravanti et al. (2007) carried out a parasitological survey to monitor activities on the sanitary status of fish cultured in Kenya. Parasites were detected in 93.3 percent of the *C. gariepinus* sampled in Kenyan dam impoundments and earthen ponds. All farmed catfish tested positive for *Trichodinella* sp. (6.7% of the sampled fish), coccidian (46.7%), dactylogyrid (87.7%) and gyrodactylid monogeneans (6.7%).

MAJOR CONSTRAINTS FACING AQUACULTURE DEVELOPMENT IN KENYA

Various constraints impede aquaculture development in Kenya. These constraints are related to policy and socioeconomic issues.

LACK OF QUALITY SEED

No system of fish seed certification exists in the country. Thus, the quality of fingerlings produced in Kenya currently is not certified. Farmers who acquire fingerlings from recommended production centers get discouraged after obtaining low yields.

LACK OF STANDARDIZED QUALITY FISH FEEDS

Formulated fish feeds are not readily available in Kenya. Although some formulations have been tried experimentally, using locally available materials, no investor has taken up feed production due to the low level of investment in aquaculture. Affordable and cost-effective feeds are necessary to enhance the production of farmed fish. By collaborating with the private sector, governmental institutes can upscale the production of fish feeds, starting up as small-scale production units as the aquaculture sector grows and attracts industrial feed manufacturers.

POOR EXTENSION SERVICES AND TECHNOLOGY TRANSFER

The country has an inadequate number of trained personnel for effective promotion of aquaculture. The training for both the existing and potential fish farmers, especially women, has not been effectively carried out due to financial constraints and lack of an aquaculture-training facility or aquaculture center of excellence. This, notwithstanding, Kenya has greatly benefited from training programs at its universities.

LACK OF AQUACULTURE DEVELOPMENT POLICY

Kenya's economy is driven mainly by agriculture and, therefore, the government tends to put emphasis on crops and livestock production. Although aquaculture is a form of agriculture, it has often been seen as a fisheries related activity, far removed from the farm. Thus, while strengthening agricultural activities, aquaculture is usually left out. A comprehensive aquaculture policy and legislation is yet to be developed.

WEAK AQUACULTURE RESEARCH PROGRAMS

Despite its potential, aquaculture in Kenya has not been taken as seriously as capture fisheries. Therefore, research institutions and universities have not been adequately funded to undertake any significant aquaculture research. This has restricted aquaculture growth. Even where research has taken place, in most cases new research findings in aquaculture may not reach the farmers in time or not at all, due to the poor linkage between researchers and farmers.

POOR DATA COLLECTION

Aquaculture production data collection has been poor and inefficient. The absence of record keeping of farmed fish inputs, production and sales deprives the sub-sector of essential data. Baseline data are needed to ensure that interventions that bring about any improvements in production levels can be recognized.

LOW INVESTMENTS IN AQUACULTURE

Many small-scale fish farmers do not consider fish farming as an income generating activity. Perhaps this is so because they are unaware of the economic viability of aquaculture, a perception that stems from the past extension methodology that emphasized aquaculture for subsistence activities meeting nutritional needs rather than for entrepreneurship. For the same reason, the private sector has not shown much interest in aquaculture investment, despite the favorable geographical and climatic conditions the country enjoys. It is, therefore, necessary to carry out research on market dynamics and potentials and required investment levels.

PRIORITY AREAS AND FUTURE DIRECTIONS

The catfish industry, if well nurtured, can provide Kenya with a source of high quality protein, a source of income and employment. In the face of declining and unreliable wild stocks that are highly threatened by overfishing and environmental degradation, improved aquaculture production would provide an alternative source of fish to meet the increased demands of the local and export fisheries markets. To develop catfish culture into a viable industry, it is necessary to improve its productivity and increase its profitability.

One of the most important constraints is the provision of quality fish seed. Although the government of Kenya has shown its willingness to fund selective breeding for catfish improvement, funding is only allocated for the first two years. The selective breeding program is limited in scope because of weak linkages among the different government institutions. Furthermore, the capacity to handle a selective breeding program requires strengthening to ensure that competent personnel handle the improved strains at the nucleus center, multiplication centers and hatcheries. It is, therefore, necessary that the initial efforts by the government should be augmented and the capacity of research institutions strengthened. There is a need to set up and rehabilitate public hatcheries, and encourage private hatcheries with appropriate and modern technologies to ensure good quality seed all the time.

Kenya is currently an active member of the East African Community (EAC), others being Uganda, Rwanda, Burundi and Tanzania. These countries share a lot in common including a common EAC parliament. By including an international dimension into the management and execution of the breeding program, the EAC countries could benefit as well, both in terms of expertise and in the acquisition of improved seed. It is suggested that regional centers where the selected lines could be tested be chosen in each of the EAC countries and that a team of scientists, extension officers and farmers be trained on aspects of selective breeding and catfish husbandry.

With increasing aquaculture activities, feed production is fast becoming an important commercial undertaking in its own right and it is expected that many private entrepreneurs will venture into the feed industry. It is necessary that government agencies play a significant role as a quality control and monitoring watchdog. This will protect the rights and interests of small-scale farmers by ensuring that only certified feeds are in the market. Provision of quality feeds is a sure way of ensuring that the improved strains are able to fully realize their potential. Through public-private sector partnerships, feed mills should be set up to produce en mass and test formulated feeds from research institutes.

An elaborate aquaculture policy in the country will ensure an efficient legal framework for the dissemination of the improved strain. Rules governing the aquaculture sector should recognize the need to inspire private investment and increase the rate of commercialization, while ensuring wise use of resources. Thus, incentives for aquaculture and elaborate rules and regulations on movement of strains and prevention of escapes are required.

Increasing the exchange of information and facilitating linkages between research and extension services in Kenya and throughout the East African Community (EAC), and with countries with successful catfish production in Africa and Southeast Asia would be beneficial. Kenya has an inadequate number of trained personnel for the effective promotion of aquaculture. An aquaculture training center or aquaculture center of excellence should be established at the national or regional level to strengthen this pool of human resources.

CONCLUSION

There is considerable potential for fish farming in Kenya due to the country's natural endowment; both climatic and geographical features are conducive to aquaculture. The slow growth of aquaculture, therefore, can be attributed but not limited to lack of a guiding policy, perception of its benefits as a subsistence activity as opposed to a viable commercial enterprise, ineffective extension strategies and technology transfer, low government funding, and inadequate investment. In the recent past, however, fish farming, especially catfish farming, has shown remarkable signs of growth and development, all attributed to the realization of its profitability and the keen interest of research institutions to develop appropriate technologies. In particular, the catfish selective breeding program should be supported to fully realize the breeding objectives of the country.

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STATUS OF CATFISH PRODUCTION IN MALAWI

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ABSTRACT

Malawi capture fisheries have drastically declined. The focus of the nation is now on aquaculture as a viable option to increase fish production. The commonly cultured fish, tilapia species, have been blamed for slow growth largely because of precocious breeding habits. Introduction of fast-growing exotic culture species has been restricted due to a fear of their potential negative impact on the biota and complex ecosystems of Lake Malawi. The main focus is to screen fast-growing indigenous species for aquaculture. Catfish has been identified as a promising fish for aquaculture because of its rapid growth rate. There are five catfish species found in Malawi including, *Clarias gariepinus, Clarias liocephalus, Clarias ngamensis, Clarias stappersii* and *Clarias theodore,* of which *Clarias gariepinus* is the most popular catfish species cultured. Catfish species are cultured in polyculture with tilapia. The current production of cultured catfish is constrained by the inadequate supply of fingerlings. There are very few hatcheries producing catfish fingerlings and the survival rates in these hatcheries are very low. Prospects for catfish culture are encouraging, following existing high market demand, development of secondary industries such as the manufacturing of fish feed, and commitment from the government of Malawi to promote its development. Despite these prospects, there is an urgent need to perfect the technologies for nursing the hatchlings and ensuring grow-out for marketing. In addition, catfish production should go in tandem with a breeding program that will improve its performance under various culture environments. Past and current research activities are highlighted in the paper. Priority areas in catfish culture include promotion of its production, encouragement of private sector involvement in fingerling production and grow-out fish production, as well as the development of a brood stock management and breeding program.

INTRODUCTION

Fish play a very important role in the socioeconomic development of Malawi, providing much needed protein and generating employment for those engaged in fishing and fisheries-related activities. Fish contribute about 60–70 percent to the nation's annual animal protein supply and provide livelihoods to over 10 percent of the nation's population. However, fish from capture fisheries have declined significantly. In light of this, the focus of attention is now on developing aquaculture as a viable option to increase fish production. However, the aquaculture sector in Malawi contributes about 2 percent to national fish production and an average productivity of 700 kg/year is very low (Malawi Government 2005). The commonly cultured fish, comprising the tilapia species, have been blamed for slow growth largely because of their precocious breeding habits. The introduction of exotic culture species has been restricted for fear of their accidental entry into Lake Malawi and their potential impact on the biota and complex ecosystems of the lake. Therefore, emphasis has turned to the development of other indigenous species with an aquaculture potential, such as African catfish. *Clarias gariepinus* was identified as the most promising candidate for Malawian aquaculture with potential yields of more than three times the fastest growing tilapia species such as *Oreochromis niloticus* (Haylor 1992). Catfish species are now one of the four commonly cultured fish species in Malawi.

OVERVIEW OF COUNTRY PRODUCTION

Aquaculture production in Malawi was estimated at 800 tonnes in 2002 and catfish contributed 5 percent to the total production (Malawi Government 2005). Yields ranging from 4.47 to 4.75 tonnes per hectare were obtained in the Northern region of Malawi from polyculture with tilapia cultured in a semi-intensive system and fed maize bran at 3 percent of body weight (Maluwa et al. 1995). The national production of catfish has been increasing, from 5 tonnes in 1996 to 17 tonnes in 2003 (Table 1).

CATFISH BREEDING

Currently, there is no catfish breeding program in Malawi. However, proper management of catfish brood stock has now been planned to be one of the activities at the National Aquaculture Center. Other stations have infrastructure that would facilitate participation in a catfish breeding program. Such facilities are found at the Bunda College Aquaculture Farm, Mzuzu Fish Farm and Kasinthula Fish Farm.

CATFISH FINGERLING PRODUCTION SYSTEMS

Three governmental hatcheries at the National Aquaculture Center, Mzuzu Fish Farm and Kasinthula Fish Farm have the capacity to produce catfish fingerlings. However, the number of fingerlings produced in these government hatcheries is still very low. The major challenge at these hatcheries is the low survival rate from the fry to fingerling stages. A low survival rate of less than 10 percent has been very common. In 2000, the National Aquaculture Center with technical support from a JICA Aquaculture Project, improved the survival rate to about 30 percent and produced over 20,000 fingerlings in 2000 (JICA 2001) and 16,905 in 2001 (ADiM 2005a). Despite technical support from a number of development partners to promote the development of catfish in Malawi, no significant take off occurred in the culture of the species. Most of the efforts were limited to spawning and not much was done to develop nursing technologies that would improve the survival rate of fry. Currently, the government, with technical support from FAO, is supporting the establishment of privately owned small-scale hatcheries in all three regions of the country.

CATFISH PRODUCERS

Catfish species are the fourth type preferred by fish farmers. Other popular fish include *Oreochromis karongae, Oreochromis shiranus,* and *Tilapia rendalli*. Catfish species are favored because of their large size and high price (ADiM 2005a). However, information on catfish producers in Malawi is very limited. There are no reports on large-scale catfish producing enterprises in Malawi. Catfish species are cultured by small-scale fish farmers instead. The survey by JICA (2004) indicated that catfish were farmed by 16 percent of the farmers in the Southern Region of Malawi. These farmers obtain their fingerlings from government stations and from the wild. Sometimes catfish are unintentionally introduced into the fish ponds.

PRODUCTION SYSTEMS

The culture of catfish in Malawi has been restricted to extensive pond culture. Catfish species are mainly cultured in combination with Malawi's major cultured tilapia species, namely *Oreochromis shiranus, Oreochromis*

Table 1: Estimated production levels (tonnes) and value (US$) of catfish (Clarias gariepinus) in Malawi between 1996 and 2003

Estimated units	Year							
	1996	1997	1998	1999	2000	2001	2002	2003
Production (tonnes)	5	7	10	12	15	18	10	17
Value (US$, '000)	5.5	7.7	12.0	14. 4	18.0	18.0	11. 2	17.0

Source: FAO 2003.

karongae, Oreochromis mosambicus and *Tilapia rendalli.* The mean body weight of *Clarias gariepinus* in polyculture with *Oreochromis karongae* at the Mzuzu Fish Farm was only up to 100 g after 168 days of culture when fed with maize bran (Maluŵa et al. 1995). Unpublished reports at the Kasinthula Fish Farm indicate that catfish stocked at a very low density of 1,000 fish/3.4 hectares attained a body weight of 1.5 kg after one year when existing in polyculture with *Oreochromis mossambicus* (JICA 2004).

MARKETING SYSTEMS

There is a paucity of information as far as catfish marketing is concerned. Demand for catfish exists in most markets, except in a few isolated communities where religious beliefs and attitudes restrict its consumption. Cultured catfish are usually sold fresh at the farm gate and are purchased by local people living within the vicinity of the pond. The prices range from MK80 to MK100 (Department of Fisheries unpublished Monthly Reports) and vary from one place to another. However, the price is very high if sold smoked. This implies that if catfish production is to be profitable, considerable work should be done on the marketing aspects, with an emphasis on adding value to the product.

CONSTRAINTS TO CATFISH PRODUCTION

The limited supply of fingerlings has been a major constraint to catfish production. A survey conducted by ADiM (2005b) found out that 98.6 percent of the fish farmers had difficulties obtaining fingerlings.

Appropriate feed for the culture of catfish posed another challenge to the culture of catfish in Malawi. In 2005, the cost of imported fish feeds was as high as $450 per tonne (ADiM 2005b). The private company, MALDECO, has installed a fish feed manufacturing plant to produce mainly tilapia feed. It is uncertain whether the production capacity of the plant would satisfy the sector’s demand. Several other small-scale feed manufacturing units are being established country-wide. However, these small-scale fish feed producers lack basic feed formulations. In addition to the availability of appropriate fish feeds on the market, the existing feeds are expensive. The cost of fish feed is around MK100/kg and the feed conversion ratio of around two obtained with tilapia suggests some refinement in the feeds. In fact, fish feed comprises about 70 percent of the total cost of fish production.

PAST AND CURRENT RESEARCH ON CATFISH

BIOLOGY: ALL ASPECTS RELATED TO THE BIOLOGY OF CATFISH SPECIES

Early observations made on catfish species in Malawi found that the fish can attain large sizes with an angling record of 16.1 kg (Skelton 2001). The fish tolerate a wide range of environmental conditions, such as salinity ranging from 0 to 12 ppt and temperatures from 8ºC to 35ºC. Trials in Northern Malawi showed that the growth rate was not affected even at temperatures below 21ºC (Maluŵa et al. 1995). It has wide tolerance of pH, turbidity and densities (Hecht et al. 1988). In fact, some catfish species were the last remaining in dry water bodies when Lake Chilwa dried up in 1996 (EAD 2000). For example, *Clarias gariepinus* is capable of breathing atmospheric air through a subranchial organ and can survive for days in air as long as it is in a moist place. The fish can move overland under damp conditions by extending its pectoral spines and crawling (Teugels 1995).

CATFISH SPECIES, STRAINS OR POPULATION FOUND IN MALAWI

Catfish species found in Malawi mainly belong to Bagridae and Clariidae with most of the cultured catfish belonging to the latter. The external morphology of clariid catfish is characterized by an elongated body with long dorsal and anal fins and the presence or absence of an adipose fin supported by elongated neural spines (Teugels 1983).

Five catfish species are widely distributed in Malawi and these include *Clarias gariepinus, Clarias liocephalus, Clarias ngamensis,* *Clarias stappersii* and *Clarias theodore* (Snoeks 2004). *Clarias gariepinus* is, however, the most popular cultured catfish species in Malawi. Other species are found in ponds in isolated cases in Northern Malawi and Lower Shire River in the Southern Region of Malawi. Most of these were unintentionally introduced through pond inlets.

BREEDING OF CATFISH

Breeding of catfish is related to water temperature. Spawning takes place at temperatures above 18°C, usually above 22°C (Hecht et al. 1988). The size at sexual maturity varies from 150 to 800 mm in total length at an age of one to three years (Hecht et al. 1988). Gonadal maturation is associated with increasing water levels in temperatures and the photoperiod. Spawning occurs during summer dark nights, usually after a rain. *Clarias* produce between 50,000 and 200,000 eggs (Hecht et al. 1988). In Malawi, the spawning period observed spans from October to March (JICA 2001 and 2004).

Since the fish do not reproduce easily in captivity, several methods have been applied to help the fish to breed. Small-scale fish farmers in Malawi were able to breed catfish using natural methods (personal observation). In addition, artificial propagation with hormones has been successful at the Kasinthula Fish Farm (JICA 2004). Its wide application in Malawian aquaculture has been difficult because of the high cost of hormones, mostly fish gonadotropins; acetone-dried carp pituitaries sold at $279 per gram (JICA 2004). The most cost-effective synthetic releasing hormones (LHRHa and GnRHa) (Harvey and Carolsfeld 1993) might be a practical choice in Southeast Asia, but they are not popular in Malawi because of the high cost of importing the hormones. The National Aquaculture Center utilized pituitary glands from the common carp kept at the center (JICA 2001). Although the use of the common carp pituitary in catfish breeding was cost-effective, the efficacy of the pituitaries varied for various reasons, such as the variation in the manual removal of the pituitary gland, improper drying of the gland, and presence of harsh climatic conditions during storage. The JICA Aquaculture Project successfully applied and developed the procedure for spawning the fish by using fresh male catfish pituitary glands (JICA 2004). However, the wide application of the method is limited due to the need for a large number of male catfish to be sacrificed for their pituitary glands.

FEED AND NUTRITION

Clarias gariepinus is omnivorous and scavenges on virtually any available organic food source including other fish, birds, frogs, small mammals, reptiles, snails, crabs, shrimp, insects and other invertebrates, as well as plant matter such as seeds and fruit. It is even capable of straining fine plankton (Skelton 2001). The growth performance of this catfish species is not related to warm water as is the case with most other fish cultured in Malawi. This suggests that the fish is capable of growing under low temperature conditions as long as food is available. However, very little work has been done on the chemical analysis of the locally available animal feeds because of the lack of adequate and reliable laboratory facilities (Safalaoh 2002).

LOCAL FEED RESOURCES FOR CATFISH FEED PRODUCTION

AGRICULTURAL BY-PRODUCTS FOR CATFISH FEED

Agricultural by-products (from both crops and livestock) provide potential locally available sources of catfish feed. The national production of selected agriculture products whose by-products could be utilized in formulating catfish feed is summarized in Table 2. In addition, livestock and fish products are potential sources of animal protein in catfish production. Malawi has a total population of 765,000 cattle, 1.7 million goats, 500,000 pigs and 120,000 chickens (Government of Malawi 2004).

Table 2: Agriculture production during the 2001–2002 growing season

Commodity	Scientific name	Quantity ('000 tonnes)
Maize	*Zea mays*	1,625,985
Rice	*Oryza sativa*	94,215
Sorghum	*Sorghum bicolour*	39,155
Cotton	*Gossypium hirsutum*	41,463
Wheat	*Triticum aestivum* L.	1,520
Ground nuts	*Arachis hypogaea*	759
Soya beans	*Glycine max*	31,373
Pigeon pea	*Cajanus cajan*	105,315
Cowpeas	*Vigna unguiculata*	26,119
Bambara nuts	*Vigna sub terranean*	7,039
Chickpea	*Cicer arietinum*	1,811
Sunflower	*Helianthus annuus*	4,107

Source: Guide to Agricultural Production and Natural Resources Management in Malawi, 2002.

CATFISH FEED INGREDIENTS

Fishmeal is one of the commonly used animal protein sources in catfish feeds. Fishmeal production in Malawi is very low. Dwindling fish catches from natural waters do not satisfy the increasing demand and not much fish remnants are available for fish feed. As such, fishmeal is very expensive. Safalaoh (2002) reported a fishmeal unit cost of $0.46/kg compared with $0.25 for full fat soya bean meal. Assuming the crude protein content of 60 percent for fishmeal and 38 percent for full fat soya bean meal, protein from these sources cost $0.77 and $0.66 per kilogram, respectively. Most of the fishmeal used is imported from other countries such as South Africa and Chile.

Use of animal by-products from processing plants and slaughter-houses, such as blood, meat and bone meal is limited due to the low supply (Safalaoh 2002).

Soya bean meal is the most popular source of protein in fish feeds. Soya bean production in Malawi was low in 1990 because of the low price of the commodity on the market. However, in recent years, the production has perked up significantly, following the high demand for it by animal feed producers. Fish farmers are realizing the importance of feeding fish with soya bean-based feeds. They are advised to combine one part of soya bean meal to nine parts of cereals (maize bran). Trials are underway to develop plant-based fish feed formulations using soya bean as one of the main sources of protein.

Other oilseed meals and grain legumes that could be utilized in catfish feed include sunflower cakes, cottonseed cakes and groundnut cakes, pigeon peas, cowpeas and chickpeas. However, their use could be limited by inadequate supply.

PRIORITY AREAS AND LIKELY FUTURE DIRECTIONS

PROMOTION OF CATFISH PRODUCTION

The special air-breathing characteristics, together with extra hardiness and rapid growth to large size, make the fish an extremely suitable species for aquaculture development in Malawi. Catfish is one of the four fish species promoted for culturing in Malawi. Since most fish farmers are sparsely distributed, the ability of catfish to utilize atmospheric air enables transportation of this fish over long distances without a special oxygen-supplying facility. The catfish's ability to prey on other fish could be used as a means to control tilapia reproduction to avoid overcrowding in fishponds. Once the problem of nursing fry to the fingerling stage is solved, catfish production is likely to boom significantly.

PRODUCTION SYSTEMS

Malawi is committed to implement research programs on this species. The major focus will be on developing breeding and rearing technologies, conducting research on catfish feeds, and on growth performance of catfish in polyculture systems with tilapia species. Project results by ADiM (2005a) indicate that the polyculture of *Clarias gariepinus* with *Oreochromis shiranus* leads to larger *Oreochromis shiranus* as a result of reduced competition for food and an increased production of *Clarias gariepinus*. The National Aquaculture Strategic Plan (2006–2011) (Government of Malawi 2005) recommended aggressive promotion of the polyculture of *Clarias gariepinus* and *Oreochromis shiranus* as a future viable alternative aquaculture production system for Malawi. It further recommended the

National Aquaculture Center to initiate on-farm participatory trials to produce fingerlings.

HATCHERY OPERATIONS

The government encourages private sector participation in catfish fingerling production. It needs to develop guidelines that will guide hatchery operations nation-wide in order to accredit catfish fingerling hatcheries. The government of Malawi, with support from FAO, implemented a technical cooperation program to support small-scale catfish fish farming enterprises as one such effort to develop small-scale catfish hatcheries. Future directions will need to scale up the hatchery and grow-out activities for catfish.

BREEDING

The promotion of catfish production will be pursued in parallel with the development and implementation of a national catfish breeding program.

CONCLUSION

Catfish species offer a promising opportunity to contribute to food security and socioeconomic development of the nation. However, incorporation of catfish production into aquaculture in Malawi has been relatively slow. Prospects for its development are encouraging because of the existing high market demand, development of secondary industries such as fish feed manufacturing, and commitment from the government to promote its development. Despite these prospects, however, there is an urgent need to perfect the technologies for on-farm production. In addition, catfish production should go in tandem with a breeding program that will improve its performance under various culture environments.

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STATUS OF AFRICAN CATFISH FARMING IN NIGERIA

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ABSTRACT

This paper presents the status of the catfish farming industry in Nigeria. The industry is responsible for 70 percent of aquaculture production, *Clarias gariepinus* being the most widely cultured species. Production of fingerlings and feed, especially floating feed, are major constraints that pose significant challenges to the industry. Priority areas and likely future directions are suggested.

INTRODUCTION

Nigerians consume an estimated 1.3 million tonnes of fish annually with a per capita consumption of 7.512 kg. Meanwhile, national production from both capture fisheries and aquaculture stands at 450,000 tonnes. Over 800,000 tonnes of fish are imported to meet the annual demand (AIFP 2004a). Catfish farming and, indeed, aquaculture offer strong potential for growth to meet the national fish demand, thereby reducing importation, providing employment, alleviating poverty, and helping to meet the Millennium Development Goals. This potential is great because Nigeria is endowed with over 12 million hectares of inland water and suitable soil for fish farming. After the Fish for All Summit of 2005 in Nigeria, the awareness and interest in fish farming has increased tremendously. Over 5,000 prospective farmers have been trained in nation-wide fish farming workshops in five geo-political zones of the country with as many as 40 percent adopting the practice almost immediately. The federal government recently launched the implementation of the Catfish Industry Value Chain Development through a $34-million[5] loan facility through the World Bank (public-private partnership initiative). This highlights the growing importance of the catfish industry in Nigeria.

The catfish species that are cultured include *Clarias gariepinus, C. anguillaris, Heterobranchus bidorsalis, H. longifilis, C. isheriensis, C. submarginatus, Chrysichthys nigrodigitatus, Bagrus* sp. and *Synodontis* sp., but *C. gariepinus* is undoubtedly the fish of choice for farmers. *C. gariepinus* is the most cultured fish in Nigeria and, indeed, Africa, and third in the world (Garibaldi 1996). It can then be inferred that Nigeria is the highest global producer of this clariid catfish. Research on the development of farming technology of *C. gariepinus* has been carried out in Europe (i.e. Belgium and the Netherlands) as well as in Africa, namely the Central African Republic, Ivory Coast and South Africa (Hetch et al. 1996). Nigeria has benefited the most by far from these research activities due to several factors: the high demand for fish from almost 140 million Nigerians; the fish being found in every part of country and relished compared to carp and tilapia that were first introduced for aquaculture in Nigeria; and the maintenance of its quality when smoked dried. Its hardiness is due to the presence of an air-breathing organ, its omnivorous feeding habit, and ability to withstand adverse environmental conditions. In addition, its high fecundity and the availability of mass artificial seed techniques (Haylor 1992; and Hecht et al. 1996) facilitate its culture without fear of overpopulation by uncontrolled breeding, such as in tilapia. The diversification of culture environments including concrete

[5] All figures given as dollars ($) refer to US dollars.

tanks, fiber glass tanks and, more recently, water re-circulation systems (WRS) have resulted in catfish production overtaking tilapia culture in Nigeria.

OVERVIEW OF COUNTRY PRODUCTION

The quantity of catfish produced from aquaculture in Nigeria is grossly underestimated as a result of many factors including lack of capacity for data collection, reluctance and lack of transparency of some farm owners, and the fact that many catfish are consumed by the households that produce them. The percentage of catfish production in the total fish production over more than a decade is shown in Figure 1. There has been a steady increase in the production of catfish since the mid-nineties. Catfish accounts for 70 percent of fish production from aquaculture in Nigeria.

PRODUCTION SYSTEMS

Catfish farming can be divided into two broad categories depending on the organization, input and level of intensification. The first category is the small-scale farmer that practices catfish farming as a sole business or on a part-time basis, employing relatively unsophisticated techniques. The part-time farmers are the most common. Feed consists mainly of household or farm waste, compounded or in an earthen fishpond, depending on fertilization and natural production. The levels of intensification are low and, consequently, so are the yields. The second group is the large commercial farmers that produce catfish using tanks with varying degrees of aeration and re-circulation. Among this group are highly sophisticated intensive re-circulation systems developed with foreign technical assistance. These commercial farms are mainly concentrated in and around urban centers and use imported brood stock (Dutch Clarias) and feed. The International Finance Corporation (IFC), a World Bank group, has predicted that catfish production in Nigeria will increase by 40,000 tonnes before 2010 with $160 million in income (IFC 2007). There is a need and much scope for research on the possibilities of establishing efficiently run large-scale sole catfish enterprises because the present ones are integrated with other agro-allied industries.

According to a 2003 survey (Aquaculture and Inland Fisheries Project 2004a), there are 2,658 fish farms in Nigeria, 2,152 of which culture catfish alone or in polyculture with *Oreochromis niloticus* and *Heterotis niloticus*. Generally, 77 percent of these farms are found in the south of the country. The regional distribution of catfish farms in Nigeria is shown in Figure 2. The southwest geopolitical region has the highest number of farms followed by south-south (mainly in the Delta State). It is important to note that the high number of farms in the south-south is mainly due to the terrain (i.e. riverine

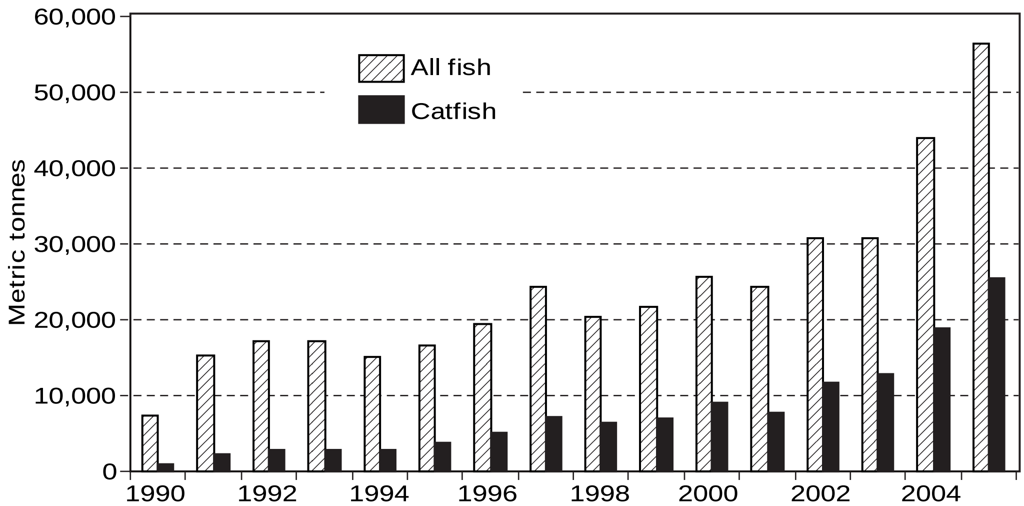

Figure 1: Annual fish production from aquaculture in Nigeria (FAO 2007)

floodplain) with many natural ponds that are put to use by the people. The northeast has the lowest number of catfish farms due to the supply of cheaper fish from capture fisheries in Lake Chad. In the southwest, catfish farming is so developed that most farmers practice monoculture and have formed themselves into associations and cooperatives. Some of these associations date back to the late 1980s. A study of some fish farmers in Oyo state (southwest) showed that the majority (46.7%) of the respondents make use of earthen ponds, while 20 percent and 33 percent use flow-through and re-circulation ponds, respectively (Olagunju et al. 2007).

Various receptacles including earthen ponds, tanks made of concrete, fiber glass, plastic and aluminum are used in farming catfish in Nigeria with culture environments ranging from extensive with little or no supplemental feeding to intensive with a complete water re-circulatory system. Two main systems are presently popular in Nigeria, the pond and concrete tanks, but there is a growing trend towards the use of concrete tanks with or without aeration as they ensure water conservation, reduce feed wastage and facilitate better management. The advantages of the recently applied water re-circulation system over the simple well-aerated concrete tank are yet to be proven. The gradual change in Nigeria from the earthen pond system to the concrete tank system is one of the factors for the rapid development observed in the industry over the last few years.

SEED PRODUCTION

High quality catfish seed in large quantities is important to the development and sustainability of the growing catfish industry in Nigeria. Although there is no breeding center in Nigeria, there are several federal- and state-owned hatcheries. Most catfish seed production is from small-scale operators and a few large commercial farms. Since the government hatcheries are either in a state of disrepair or are producing below capacity, this creates an opportunity for private investment in seed production. The distribution of these hatcheries is shown in Figure 3. The number from the southwest is underestimated, because no data are available for the states of Oyo and Osun which have a substantial number of catfish farms.

Fingerling production in Nigeria has increased ten-fold from 3-million/year in 2000 to an estimated 30 million in 2005, making fingerling sales valued at an estimated $2.32 million (AIFP 2005). Much of the seed are produced by small-scale hatcheries that produce between 60,000 to 200,000 fingerlings annually, using mainly the Ovaprime hormone during the three to five months of the normal catfish breeding season (i.e. May-September). These small hatcheries have been shown to have a profitability index in the range of 0.49-2.52 (Olagunju et al. 2007). The five large hatcheries, on the other hand, produce around 3-4 million fingerlings all year-round, using a controlled induced spawning method

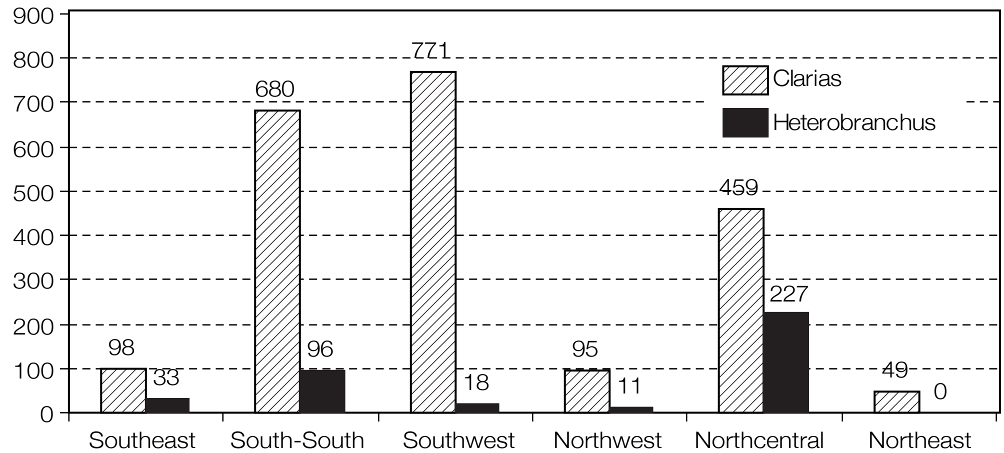

Figure 2: Regional distribution of catfish farms in Nigeria (Based on AIFP 2003 survey)

in an intensive re-circulating system. The price of a 2-3 cm fingerling sells for $0.11 each on average, while those of 4-6 cm cost $0.23 each.

The small-scale producers are driven mainly by profit and care little about the quality of their seed. Many hatcheries either collect brood stock from the wild or use siblings of the previous year's production with attendant inbreeding and introgression. As there is no way a grow-out farmer can detect poor quality seed at the point of collection, many procure fry or fingerlings with poor growth and survival rates. This problem has discouraged many grow-out farmers or made them go into seed production with little or no knowledge of genetics and fish breeding.

MARKETING SYSTEMS

The marketing structure of catfish culture is mainly informal and, therefore, economic data are not available. Catfish from aquaculture in Nigeria are sold fresh. For the large commercial farms, sales are made throughout the year, often on a weekly basis. But most farms harvest the catfish on an irregular basis in an "all-in-all-out" manner. This sometimes results in a glut as most farmers breed catfish during the rainy season and harvest some six months after. Meanwhile, some private individuals have started fish processing and storage specifically targeting the industry. Their strategy is to work through a catfish farmers' association to get farmers to utilize their processing facilities. Presently, the country is the largest market for farmed catfish as there is still a huge demand, even though the annual production pattern is skewed to a few months in the year. The market price for a kilogram of fresh catfish currently ranges from $2.70 to $3.10 while smoked dried ones are higher.

FEED AND NUTRITION

Nigeria produces around 3.4 million tonnes of animal feed annually, although the majority of this is for the poultry industry. Less than 1 percent (25,000 tonnes) of this feed is for fish (AIFP 2004b). Catfish feed is the second most important input in the industry after the seed, accounting for up to 40 percent and 60 percent of the production cost, respectively (Fagbenro 1987; Satia 1990). *C. gariepinus* has a relatively high dietary protein requirement. Feeding with a formulated feed is a prerequisite for intensive monoculture of the African catfish. The best growth rates and food conversions are achieved with diets containing 35-42 percent of crude protein and a calculated digestible energy level of 12 kJ g^{-1} (ADCP 1983). A review of the animal and aquafeed industries in Nigeria made by Fagbenro and Adebayo (2005) revealed that most catfish feeds are farm-made, using locally available ingredients such as maize, soya bean, fishmeal, blood meal, rice bran, fish oil and wheat offal. Other unusual feedstuffs include maggots, termites, earthworms and crickets. There is presently no exclusive aquafeed mill, and commercial catfish feeds are produced by livestock millers in small quantities and mostly on demand. In

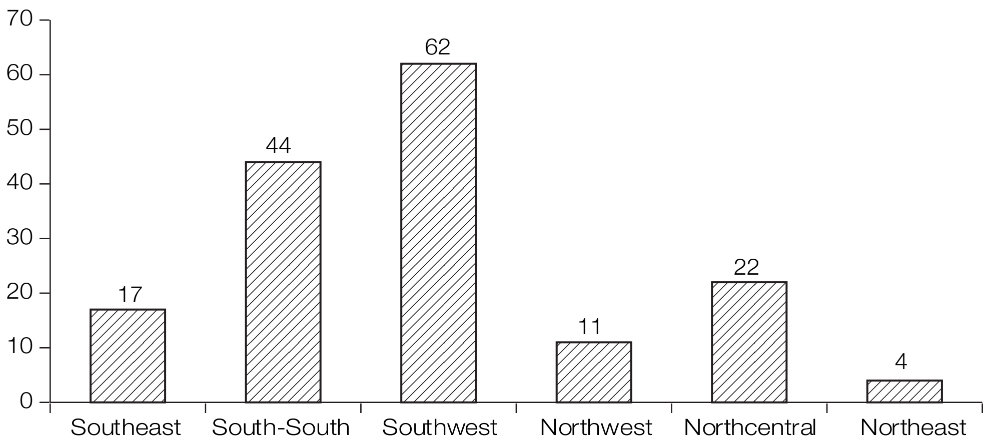

Figure 3: Regional distribution of catfish hatcheries in Nigeria (Based on AIFP 2003 survey)

recent years, an estimated 4,000 tonnes of commercial fish feed were imported annually from Europe, mainly from Denmark and the Netherlands.

RESEARCH AND TRAINING IN AQUACULTURE

Fisheries research and training are the responsibilities of Fisheries Research Institutes and their affiliated colleges, although federal and state Department of Fisheries also contribute to human resources development through short-term training programs and sponsorship of trainees. The Nigerian Institute for Oceanography and Marine Research (NIOMR) is the agency of the federal government established to conduct research on the resources and physical characteristics of Nigerian territorial waters and the EEZ. Its activities among others include brackishwater aquaculture research. African Regional Aquaculture Center (ARAC), at Aluu, Port Harcourt, is a substation of NIOMR where its brackishwater aquaculture research and training activities are based. The Federal College of Fisheries and Marine Technology (FCFMT), Lagos, started as a division of NIOMR, but is now autonomous and has a mandate to train middle-level experts for the fisheries sector.

The National Institute for Freshwater Fisheries Research (NIFFR), New-Bussa, has the mandate for inland water resources and freshwater aquaculture. Research on catfish farming technology at this institute dates back to the early 1980s with work on *Clarias anguillaris* and in the 1990s on *C. gariepinus, Heterobranchus* and their hybrids. The Federal College of Freshwater Fisheries Technology (FCFFT), New-Bussa and Baga, is based on the shores of Lake Chad. Both of these colleges train middle-level experts on inland capture fisheries technology and aquaculture management. Many universities in Nigeria are involved in training and research on fisheries and aquaculture, but currently none is dedicated solely to catfish research.

PAST AND CURRENT RESEARCH ON CATFISH

BREEDING AND GENETICS

The culture of catfish, like every species, depends, among other things, on sound brood stock management and the continuous selection of desirable traits. *Clarias gariepinus,* the desired culture species, is closely related to *Clarias anguillaris,* both belong to the same genus (Teugels 1982, 1986). The two species are sympatric in Nigeria with very little external difference between them (Benech et al. 1993; Rognon et al. 1998; and Teugels 1998) and are only distinguished morphologically by the number of gill rakers on the first branchial arch. In *C. gariepinus*, the number is high (up to 110) while in *C. anguillaris* it is lower (less than 50). In both species, the gill raker number increases with the standard length (Teugels 1986 and 1998). At the genetic

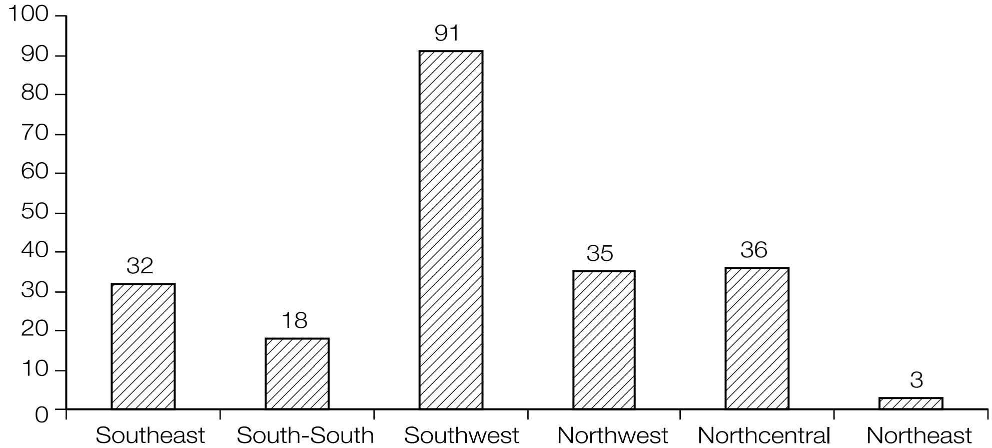

Figure 4: Regional distribution of feedmills in Nigeria (Based on AIFP 2003 survey)

level, the two species are also very close with a Nei's genetic distance of 0.16 (Rognon et al. 1998) and P distance 0.04 (Nwafili and Gao 2007). One consequence of the similarity between these two species is that many farmers are inadvertently culturing *C. anguillaris* and contaminating the gene pool of *C. anguillaris* and *C. gariepinus* through inter-specific hybridization. This suspicion was confirmed by a recent study on the genetic characteristics of the Dutch strain of *C. gariepinus* from five hatcheries in Nigeria that showed contamination of the exotic gene pool with local strains of *C. anguillaris* associated with unwholesome hatchery practices (Nwafili and Gao 2007). Apart from misidentification, Nwafili and Gao (2007) gave economic reasons for this practice, citing obtaining *Clarias* from the wild, and then maintaining brood stock coupled with the cost of exotic *C. gariepinus* fingerlings that are about 40 percent higher than those sold as *C. gariepinus*.

HYBRIDIZATION

Intra- and inter-specific hybridization studies have been conducted in Nigeria on the same catfish species (Aluko and Shaba 2000; Madu and Aluko 2000; and Dada and Wonah 2003). Madu and Aluko (2000) reported significant growth performance and survival of *C. gariepinus* x *C. anguillaris* hybrids over their parents. The F1 and F2 backcross hybrid of *H. longifilis* and *C. anguillaris* has been shown to be infertile. The comparative advantage of these hybrids and their importance to aquaculture is yet to be demonstrated.

OTHER TECHNIQUES

Some work has been done in the area of genetic manipulation of catfish, but all have been at an experimental level and have not been translated into real production. For instance, Aluko (2000) induced triploidy using the *H. longifilis* and *C. anguillaris* hybrid. According to Olufeagba et al. (2000a), using temperature to induce triploidy in *H. longifilis*, the best results from cold shocking of fertilized eggs were obtained at 5ºC for 40 minutes while 39ºC for 3 minutes was the optimum for warm shock. The survival percentage of triploid fingerlings was 88.8 percent, compared to 51.3 percent for diploid fingerlings. The result from induced diploid meiogynogenesis of *H. longifilis* showed 25 percent hatchability, compared to 53 percent for normal fish (Olufeagba et al. 2000b).

PRIORITY AREAS AND LIKELY FUTURE DIRECTIONS

POLICY AND LEGISLATION

Presently, there is no aquaculture policy while the sole piece of legislation on it deals only with the importation of exotic species. The development of the correct policy and legislation is an essential aspect that must be in place for effective and sustained development of the industry. Even when these policies and laws are in place there will be a need for a body to ensure enforcement, as experience has shown from existing fisheries laws. In order to stem the tide of indiscriminate contamination of the gene pool of cultured catfish in Nigeria, there is need for a national center that will have the capacity to document genetic characteristics of all cultured catfish species.

Such a center would also serve as a nucleus breeding center where records of ancestry and crossbreeding of catfish and, indeed, of all cultured aquatic organisms would serve as a national aquaculture database. The center would have the capacity for cryopreservation of gametes for the maintenance of breeds and strains, thus saving a lot of funds keeping live fish. Regional hatcheries would obtain brood stock from this center to produce seed to meet the farmers' needs. The center and associated hatcheries should be managed on a public-private basis (better still, by an international organization with capacity in fish breeding) in order to stem inefficiency on the part of the government and prevent a monopoly on the part of a private company. The government can provide these facilities and pay staff remuneration, while the international agencies would provide funding for research activities so that they are managed effectively.

There should be legislation to stop individuals from collecting seed from the wild or any other source, except the regional hatcheries, and to prevent arbitrary cross-breeding of farmed catfish. The law should also cover prevention of escape to the wild of farmed fish. Legislation by itself may not be effective unless there is a conscious effort to promote responsible practices by strengthening catfish fishers' associations that will have the capacity for self regulation, policy advocacy, educating its members and defending the interests of the industry. These associations can also generate demand-driven research as opposed to what is presently undertaken at the research centers.

It is necessary to limit research to a few proven catfish species and research efforts should first be directed towards characterizing the genetic variability of both the wild stocks and domesticated populations. The traditional method of selective breeding has been recognized as an effective means of improving the performance of the fish and, hence, there is a need to employ advanced genetic techniques to develop high yielding strains for the industry. This, however, will require considerable development of human resources with the requisite capability in modern genetics and genome research.

CONCLUSION

The future of catfish farming in Nigeria is bright and, compared to capture fisheries, is in a better position to improve livelihoods, provide food security, alleviate poverty and even become a foreign exchange earner. However, the government of Nigeria must put policies in place to ensure that the catfish industry is conducted in a responsible manner. This requires careful planning, implementation and management at federal, state and local government levels, with the guidance of international agencies such as the FAO and The WorldFish Center. The government should move further with the enactment of laws providing guidelines and regulations for the establishment of hatcheries, acceptable genetic technologies, reliable sources of brood stock, record keeping and environmental impact assessment of aquaculture facilities. Such measures would safeguard against unwholesome practices in the catfish industry.

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THE CURRENT STATUS OF CATFISH CULTURE AND RESEARCH IN UGANDA

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ABSTRACT

The paper discusses the status of catfish farming and research in Uganda and highlights a strategy for a catfish improvement program. It was compiled from the views and practices of aquaculture policymakers, research scientists, the main catfish hatchery proprietors and their managers, and also from literature sources. Findings show that fish farming in general is still at a subsistence level in output for grow-out, but is purely commercial for catfish hatchery operators. Catfish constitute 40 percent of the total production. There are indications that most of the farmed catfish in Uganda are the subsequent generations of a small catfish founder population that was introduced into the country from Kenya. Also, findings show that no attempts have been made to assess the quality of catfish, neither has there been any improvement program in the country. This paper gives a review of the state of catfish production, highlights the past and current research on catfish, and suggests priority areas and likely future directions for catfish improvement in Uganda.

INTRODUCTION

Aquaculture in Uganda started in 1953 with the farming of indigenous fish species (*Oreochromis niloticus* and *O. leucostictus*). It was the frustration from their precocious reproduction and, therefore, stunting in ponds that led to the introduction of the common carp (Owori[1] unpublished data). The primary objective of aquaculture development in the country at the time was to address malnutrition among the rural population. As such, fish farming has remained at a subsistence level in operation and output to date.

African catfish (*Clarias gariepinus*) has recently emerged as the most favored species for aquaculture in Uganda. It is particularly popular among fingerling producers for the bait industry. To the grow-out farmers, the main reasons given for a shift from tilapia to catfish farming are that catfish grow fast, enjoy a good market, both domestically and regionally. They are also credited with greater adaptability in poor water quality conditions than tilapia and not reproducing naturally in ponds, resulting in high yields. Catfish currently contributes up to an estimated 40 percent of the aquaculture production in grow-out ponds in Uganda.

Several constraints have been facing catfish culture in Uganda including: limited access to brood stock; lack of technology for its captive breeding, and lack of formulated feeds. Some of these problems are now being addressed. However, a number of factors such as brood stock quality and their management still remain and may be affecting the performance of catfish in the country. Research in Eastern[2] and mid-Western Uganda has revealed deformed catfish and in some cases, up to 2 percent of the fish in grow-out farms are deformed. In an attempt to understand the possible causes of these deformities, an investigation was made into the history of catfish farming in the country. It has now been found that

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[2] Uganda is divided into four administrative regions: Northern, Eastern, Central and Western.

few founder brood stocks of catfish (53) were introduced into the country from Kenya (Rutaisire[3] 2007 personal communication), from which most of the farmed catfish in the country were produced. Some catfish farmers have introduced a few males from the wild to avert the likely inbreeding effects (Digo[4] 2007 personal communication). These were, however, not genetically characterized, although the commonly held notion is that cultured catfish in Uganda is *C. gariepinus*. Therefore, catfish species or strains are not clearly classified.

Most of the fingerlings go into the bait industry, hence the biggest challenge for scientists and farmers in the country is to try and tailor catfish production for grow-out rather than increasing the fishing effort on the already dwindling stocks of Nile perch. Only then will the attention be focused on addressing the quality of catfish fingerlings produced. This paper therefore, gives a review of the state of catfish production, highlights the past and current research on catfish, and suggests priority areas and likely future directions for catfish improvement in Uganda.

Table 1: Catfish production by region in the country

Region	Production (tonnes)
Western	1,964.7
Eastern	1,333.6
Central	2,074.4
Northern	1,153.0

Source: DFR[5] (2007).

OVERVIEW OF COUNTRY PRODUCTION

Accurate estimates of actual production are difficult due to the fragmented nature of fish farming in the country, lack of proper record keeping by farmers and the inefficiency of government agricultural extension services. A spectacular trend is that in the last ten years aquaculture production and particularly catfish culture and production has been steadily increasing (Figure 1). Information from the Department of Fisheries Resources indicates that catfish production has risen to 40 percent of the total aquaculture production. Production capacity by region is given in Table 1.

INDUSTRY STRUCTURE

There is only one national-level public center, the Aquaculture Research and Development Center (ARDC) at Kajjansi with the mandate to conduct aquaculture research of national strategic importance. There are also five zonal public fish fry production centers based in different agro-ecological regions (in the northern, West Nile, eastern, western

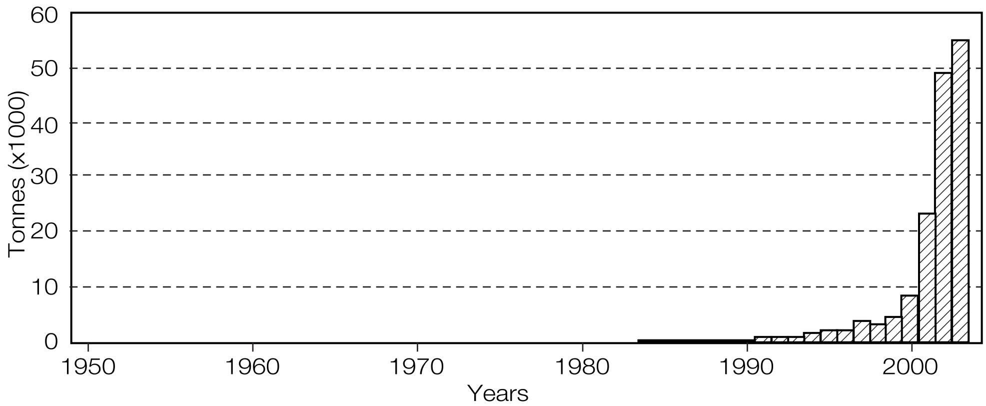

Figure 1: Total aquaculture production for the last ten years (Megapesca 2006)

[3] Dr. Justus Rutaisire is the Head, Aquaculture Research and Development Center, Kajjansi, and also a catfish hatchery operator.
[4] T. Digo is a fish farmer and the proprietor of the Sun Fish Farm, the biggest catfish hatchery in the country.
[5] Department of Fisheries Resources (DFR) in the Ministry of Agriculture Animal Industry and Fisheries.

and southwestern parts of the country) with a mandate to replicate and tailor aquaculture research to address local requirements. The zonal centers, however, lack facilities and human resources for aquaculture research, but ARDC is adequately equipped to meet research needs. Catfish breeding has not been a focus of attention until 2007. This is because the center had a limited number of staff members, and there was a perception that selective breeding in catfish was not urgently needed because the growth rate was higher compared with tilapia species in the same culture period in Uganda. Both ARDC and the zonal centers are involved in very limited fry production to supply farmers within the country and the respective regions. The regional centers have brood stocks of catfish, tilapia and a few *C. carpio,* while ARDC, in addition, has stocks of *Bagrus docmac*, Nile perch, *Barbus* species and *Labeo* species.

HATCHERIES AND PRODUCTION CAPACITY

There are a number of small part-time hatcheries, but only ten are full-time and keep records of production. The average number of brood stock is about 100. Some hatcheries do not even keep brood stock; they only buy brood stock from other hatcheries at the time they want to produce fry. Data from five regularly reporting hatcheries indicate increasing numbers of fingerlings. The total number of fingerlings produced in 2006 was estimated at one million. The total production per month in 2007 is estimated at 200,000 (FISH project[6] 2007). The range of production capability is estimated at 2,000-7,000 fingerlings per kilogram of the female's body weight. These hatcheries are all involved in induced catfish breeding. Most of them employ certificate or diploma holders with training in general fish farming from the Fisheries Training Institute, Entebbe.

Fingerlings for both grow-out and bait purposes are mostly from the five main hatcheries and, to a lesser extent, from the wild. Both small- and medium-scale hatcheries supply fingerlings without restrictions because there is no clear policy that regulates the quality of fry or fingerlings in Uganda. Unfortunately, the parental breeders used to produce fingerlings for sale and restocking their ponds are limited in order to cut down production costs. Most of the hatcheries have employed induced-breeding techniques, and some use chemicals continuously to prevent or treat diseases. For "fear of disease" outbreaks and the resulting losses that they may incur, some hatcheries keep fry in formalin throughout their hatchery life. This is beginning to raise health concerns for consumers.

PRODUCTION SYSTEMS

Up to 18 percent (43,942 sq. km) of Uganda's land mass is freshwater (i.e. major and minor lakes, rivers, swamps and reservoirs). The most commonly used production system is pond culture for grow-out, and the number of ponds has been increasing since 1999 (as shown in Figure 2 below).

Tanks are used mainly for the production of fingerlings as bait for Nile perch as well as for grow-out. Cage farming is still at an experimental level on Lake Victoria by the FISH project. An EU-funded project called BOMOSA is also experimenting with cage culture in small reservoirs in Eastern Uganda. Despite cage culture trials, there is no legislation providing for cage culture in the country and there is no factory producing high quality floating feeds for use. Trials by the FISH project are dependent on

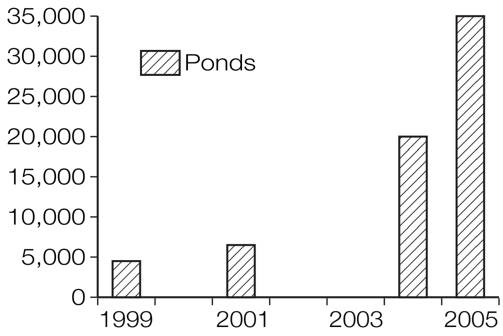

Figure 2: Increase of pond culture from 1999 to 2005

6 Fisheries Investment for Sustainable Harvest (FISH) project is a USAID-funded project in Uganda implemented by Aurban University.

imported floating feeds from the USA. It is important to note that Lake Victoria has had an incident of water hyacinth proliferation, a sign that it has a high level of nutrients. Development of commercial cage culture on the same lake with low quality feeds may lead to further eutrophication for the biggest freshwater body in Africa. BOMOSA uses sinking feeds produced in the country with high fiber content (Figure 3) that is likely to have serious water quality implications on the receiving waters.

SCALE OF PRODUCTION BY SECTORS: STATE, PRIVATE, JOINT VENTURE AND OTHERS

The majority of grow-out farmers are practicing subsistence farming. Different categories of farmers in Uganda are indicated in Table 2. Small-scale commercial farmers practice both semi-intensive and intensive levels of production.

Both subsistence and small-scale commercial farmers are private producers and use formulated feeds from Ugachick. Government institutions are involved mainly in the provision of extension services, research and, to a limited extent, fish seed production.

Table 2: Scales of aquaculture production in Uganda

Scale	Production level
Subsistence	Extensive
Small-scale commercial	Semi-intensive
	Intensive

On-farm trials in Eastern and Central Uganda show catfish yields of 18-20 t/ha with Ugachick poultry breeder feeds produced in the country. Cage production data available show yields of between 135 and 173 kg/m^3 for 1 m^3 and 2 m^3 volume cages, respectively.

MARKETING SYSTEMS

Marketing of farmed fish in the country includes pond sites, local and urban centers. Regional markets are now being targeted, especially for the fingerlings destined as bait for Nile perch on Lake Victoria among the three countries of East Africa. It is important to note that the marketing of farmed fish in Uganda is not well organized. Farmed and capture fisheries fish are all sold in the same market, at the same stalls, except for those sold at the pond site. This makes it difficult to sell farmed fish at a reasonable price when compared with fish from capture fisheries, considering the high production costs involved in fish farming. However, efforts at the research center to teach farmers to smoke their fish, which increases both the shelf-life and their earnings, have started to pay off. Also, farmers are encouraged to sell farmed fish live. This strategy is yielding results because fish from capture fisheries is normally of rather poor quality due to the methods used in its capture and transportation to markets. Catfish is being exported to the DR Congo after getting permits from the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF[7]).

Figure 3: Ugachick Poultry Breeder's feeds before and after dissolving in water

[7] Department of Fisheries of MAAIF

Farmed fish have not yet penetrated the European Union (EU) market because of the stringent EU standards set, but the Government of Uganda is hopeful, since the same market accepts fish from Uganda's capture fisheries.

PROBLEMS, ISSUES OR CONSTRAINTS

The challenges of catfish farming in the country still remain, but plans and efforts are underway to address them. These challenges include:

- Very low survival both in the hatchery and grow-out farms
- Lack of capacity to identify and treat emerging hatchery diseases by using incorrect or inappropriate drugs
- Deformities observed in grow-out ponds in the eastern and western parts of the country
- Little or no knowledge in genetic principles of managing brood stock among fingerling producers and extension officers
- The quality of brood stock is not known or uncertain (genetic studies on farmed or wild catfish have not been done at all)
- Lack of quality feeds and inadequate quantity of feeds
- Poor and inadequate extension services
- Poor management of the production systems leading to low yields that discourage the catfish industry

PAST AND CURRENT RESEARCH ON CATFISH

There has been limited advancement in catfish research in the country. This is because the research center has been struggling with problems of understaffing, limited experience and expertise in aquaculture research, as well as inadequate funding. The following have either been accomplished or are on-going:

- Determining the economic feasibility of catfish production in Eastern and mid-Western Uganda (on-going)
- The use of "shooters" as brood stock in catfish farming: study on cannibalistic behavior and fast growth (on-going)
- Determination of the carrying capacity of catfish ponds with static water (on-going by FISH project)
- Comparative growth rate trials of *O. niloticus, C. gariepinus and C. carpio* fed on formulated diet (Kajjansi Aquafeed) and two commercial feeds in unfertilized ponds (past)
- Use of poultry waste (offal) for *C. gariepinus* culture in earthen ponds (past)

FEED AND NUTRITION

Two private companies manufacture fish feeds in the country: Ugachick Poultry Breeders Limited and NUVITA. NUVITA produces for one fish farm (Source of the Nile), while Ugachick produces and sells to all fish farmers. All the feeds produced so far are the sinking pellet type with a high fiber content. Feeds for fish larvae are imported into the country by Balton Uganda making them expensive and untenable for upcoming hatchery operators.

LOCAL RESOURCES: AGRICULTURAL PRODUCTS, LOCAL FEEDSTUFF

Agricultural products in Uganda include: sunflower, soya, maize and rice bran, millet and sorghum. The animal protein source for the feeds is mainly *Rasteneobola agentae* (mukene) that is likely to become an environmental and food security issue in the near future.

NUTRITIONAL STUDIES ON CATFISH

Nutritional studies referred to here have been conducted by Fisheries Training Institute students supervised by ARDC Kajjansi staff at the station.

- Comparative growth rate trials of *O. niloticus*, *C. gariepinus* and *C. carpio* fed on Kajjansi Aquafeed and two commercial feeds in unfertilized ponds. *O. niloticus* and *C. gariepinus* performed better on Kajjansi aquafeed followed by Ugachick and lastly Bulemezi (slow and weaker). Growth of *C. capio* was highest on Ugachick feed followed by Bulemezi. With the help of scientists from Auburn University on the FISH project, the quality of Ugachick feed has been improved.
- Use of poultry waste (offal) for *C. gariepinus* culture in earthen ponds. Results: It was feasible and economical to raise fish on offal (22.7 t/ha), but an unexpected problem was that the catfish became too fatty.

MANAGEMENT: PRODUCTION CYCLE FROM BREEDING, NURSING, REARING TO GROWING OUT

Brood stock management does not take into account genetic principles, even though attempts are made during breeding to use more than one male for egg fertilization. The tendency has been to try to match the brood stock weight of females with those of males during the operation. The male pituitary gland is used to induce the females. Some hatcheries are employing formalin (1,000 ppm) on fertilized eggs for prophylaxis against hatchery diseases. Rudimentary recirculation systems (i.e. bottle tops and aggregate stones as biofilter material) are being used in hatcheries, although others are still using the flow-through system. Feeding of fry was originally done with live feeds produced locally in the hatcheries. Later, artemia was adopted by a few well-to-do farmers and now artemia are replacing other feeds (from Balton Uganda).

Farmers use starter feeds for one month on stocked fingerlings and later switch to grower feeds for the grow-out stage. Fingerlings are mostly transported in large open plastic tanks with aeration from the hatcheries to the farms. Plastic bags in which pure oxygen has been pumped are still being used for fingerling transportation to grow-out farms. Most farmers have adopted manufactured feeds, although some are still using on-farm produced feeds due to the high cost of the former.

PRIORITY AREAS AND LIKELY FUTURE DIRECTIONS

For increased and sustainable catfish production through culture in Uganda, it is recommended that the following issues be addressed in the very near future:

- Immediate introduction of brood stock from the wild for interbreeding with those available in culture units to improve the quality of catfish fingerlings as a mitigation measure. However, a long-term plan for a selective breeding program beginning with genetic characterization of the strains in the wild and those in culture units (public sector) should be initiated.
- Collaboration with reputable research scientists and institutions worldwide to build up capacity to develop and sustain sound breeding programs
- Raising awareness of the need for good brood stock management practices amongst hatchery managers and grow-out farmers
- Working with private feed industries to address the lack of starter feeds for catfish fry and to improve the quality of grower feeds (partnership with Ugachick to avail them with an extruder are underway)
- Encouraging young scientists to train in fish health and disease management

CONCLUSION

Further development of the catfish industry in Uganda will require genetic improvement of the brood stock for key traits of commercial importance. A commitment to a long-term program of selective breeding is, therefore, needed to transfer improved genes from the nucleus to the commercial populations. Attempts should be made in areas of molecular genetics and genomics such as population characterization, linkage mapping, genome sequencing of catfish species or strains in the country. Developing capacity to use molecular markers will contribute to enhance efficiency of conventional selection methods.

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CLARIAS CATFISH: BIOLOGY, ECOLOGY, DISTRIBUTION AND BIODIVERSITY

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INTRODUCTION

Catfishes of the genus *Clarias* (Siluroidei, Claridae) are widespread in tropical Africa and Asia. Having evolved in the Pliocene epoch (upper Tertiary period) some 7–10 million years BP (Sudarto 2007), there are now 58 species recognized in FishBase (as of October 2007), all living in freshwater (Annex A), but able to tolerate salinities up to 2.2 ppt (Clay 1977). They are characterized by a rather eel-shaped body, long dorsal and anal fins, lack of a dorsal fin spine, no adipose fin (except a vestigial remnant in *C. ngamensis*) and four pairs of barbels (Figure 1).

The synapomorphic characteristic of the family Clariidae, which also includes the genera *Bathyclarias, Channallabes, Clariallabes, Dinotopterus, Dolichallabes, Encheloclarias, Gymnallabes, Heterobranchus, Horaglanis, Platyallabes, Platyclarias, Uegitglanis* and *Xenoclarias* is the suprabranchial organ (Teugels 2003), formed by folds of the second and fourth branchial arches. With this organ, which functions like a lung, *Clarias* species are able to practice aerial respiration and can thus tolerate very low dissolved oxygen and even survive long periods out of water, provided their suprabranchial organ remains moist. Even under conditions of dissolved oxygen saturation, Clariids rely on atmospheric oxygen for about 50% of their needs, increasing to 80-90% under low dissolved oxygen conditions (Moreau 1988). Juveniles, apparently due to underdeveloped suprabranchial organs, depend on dissolved oxygen for 90% of their needs (Lévêque and Quensière 1988).

ECOLOGY

Clarias species probably evolved in tropical swamp forest ecosystems (Sudarto 2007) but now occupy a wide range of habitats from cascading mountain streams and deep lakes to swampy holes. However, they are especially fond of slow-flowing lowland streams, shallow lakes, swamps, ponds, ditches, rice paddies and pools left in low spots after rivers have been in flood. Many species seem to prefer stagnant, muddy water, where their suprabranchial organ gives them a competitive advantage over species requiring higher concentrations of dissolved oxygen (Jackson et al. 1988). In larger waterbodies, *Clarias* seem to

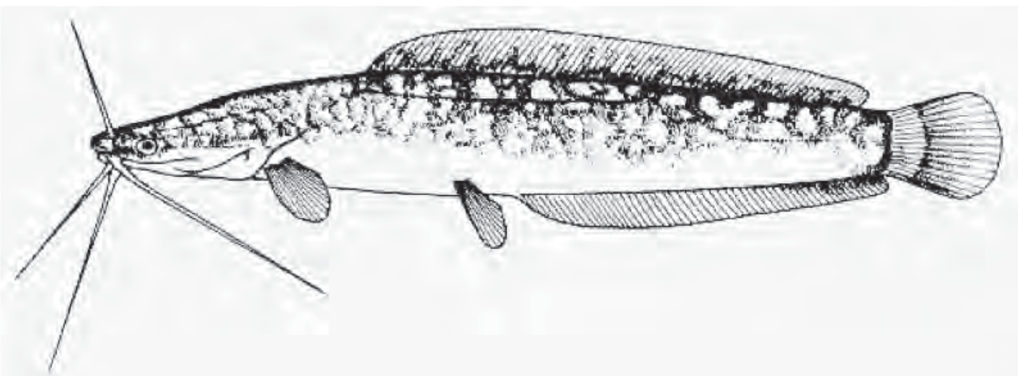

Figure 1: A typical Clarias species, *C. gariepinus* (FishBase 2007)

prefer marginal weedy areas (Daget 1988; Welcomme and de Merona 1988).

The ability to breathe atmospheric oxygen, the elongated body form and strong pectoral spines are used by *Clarias* species to wriggle over land and, coupled with the ability to leap considerable vertical distances, invade new waterbodies or escape from stressful conditions. Most such movement occurs at night.

Members of the genus *Clarias* are omnivores and are highly opportunistic feeders, taking almost anything they can fit into their mouths (Lauzanne 1988). Stomach contents of *Clarias* species typically include insects (adults and larvae), worms, gastropods, crustaceans, small fish, aquatic plants and debris, but terrestrial seeds and berries, and even birds and small mammals, have also been observed. *C. cavernicola* relies heavily on bat droppings for its nutrition. Larvae are almost exclusively dependent on zooplankton for the first week of exogenous feeding (Hecht 1996). Large *C. gariepinus*, courtesy of their high number gill rakers, have been reported to also target zooplankton as a primary food source (de Graaf and Janssen 1996). Although generally omnivorous, *Clarias* spp. are relatively better at digesting high-protein diets than carbohydrates (Wilson and Moreau 1996).

Most species of *Clarias* are slow foraging predators, with very small eyes, using their four pairs of barbels to feel their way around in the dark (Boujard and Luquet 1996) and find food detected by the array of sensitive taste buds covering the barbels and head (Garg et al. 1995). Approximately 70% of feeding activity takes place at night (Hossain et al. 1999). Research done in South Africa reported by de Graaf and Janssen (1996) showed that removal of the barbels reduced feeding efficiency in *C. gariepinus* by 23%. In general, *Clarias* catfishes capture their prey by gulping them with a rapid opening of the mouth and then retaining them either on the gill rakers or fine recurved teeth arranged on dentary, premaxillary, vomerine and pharyngeal bands (Bruton 1979).

C. gariepinus, one of the more successful *Clarias* species based on extent of its native range, exhibits a variety of feeding strategies including sucking the surface for terrestrial insects and plant fragments washed into the water by heavy rains and pack-hunting of small cichlids (Bruton 1979).

Growth in *Clarias* species is relatively rapid, with most species approaching their maximum size within a couple of years. Most *Clarias* species are relatively r-selected (altricial) with medium to high resilience (population doubling time of 15–30 months) and rapid growth to relatively early sexual maturity, high fecundity and a (anticipated) short lifespan (Hecht 1996). First year growth in the larger, k-selected species (e.g., *C. gariepinus*) is nearly linear resulting in the large initial jump in size shown in Figure 2 (de Merona et al. 1988). See also Table 1.

REPRODUCTION

Many *Clarias* species undertake lateral migrations from the larger waterbodies in which they feed and mature, according to Legendre and Jalabert (1988) at about the age of 2 years under natural conditions (but sometimes 7–8 months in captivity), to temporarily flooded marginal areas to

Table 1: von Bertalanffy growth estimation parameters for two Clarias species (de Merona et al. 1988)

Species	Location	Sex	L_∞ (mm)	k_a	T_o (years)
C. gariepinus	Limpopo	M	1,564.8	0.084	-2.35
C. gariepinus	Boskop Dam	M	1,366	0.171	-0.782
C. gariepinus	Boskop Dam	F	1,950.5	0.090	-1.090
C. gariepinus	Shire River	M	1,320	0.093	-0.737
C. gariepinus	Shire River	F	577.6	0.310	-0.383
C. gariepinus	Lake Sibaya	M	759.5	0.349	0.036
C. gariepinus	Lake Sibaya	F	672.5	0.517	1.234
C. gariepinus	Lake Are (Egypt)	M/F	1,154.9	0.110	-0.614
C. ngamensis	Shire River	M	1,147.8	0.085	1.589
C. ngamensis	Shire River	F	628.6	0.215	-0.659
C. ngamensis	Lake Liambezi	M	523.6	0.408	-2.631
C. ngamensis	Lake Liambezi	F	511.4	0.328	-3.525

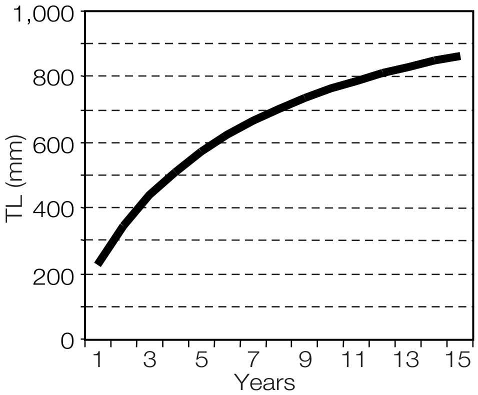

Figure 2: Composite von Bertalanffy growth curve for data shown in Table 1

breed (Seegers 1996). These reproductive migrations typically take place shortly after the onset of the rainy season(s). Predictive cues for gonadal maturation include increasing temperature, photoperiod and electrical conductivity, while proximate cues for final maturation are associated with rising water levels (Legendre and Jalabert 1988; de Graaf and Janssen 1996).

Under stable environmental conditions, some species (e.g., *C. gariepinus, C. fuscus*) have mature gonads year-round and are capable of reproduction (Young and Fast 1990). Under ideal conditions, the ovary of a ripe female constitutes 15–20% of body weight, with about 600 ova per gram of ovulated eggs (de Graaf and Janssen 1996). Ovarian anatomy in *Clarias* is typical for teleostians. The testes, on the other hand, are peculiar, being divided into two parts: an anterior functional testes and a posterior cluster of seminal vesicles, the role of which is not precisely understood but which may contribute to sperm longevity and motility (Legendre and Jalabert 1988). In terms of gonadal activity, males appear to be less sensitive to temperature fluctuations than females (de Graaf and Janssen 1996).

Prior to mating, males have been reported to compete aggressively for females with which they mate in single pairs (de Graaf and Janssen 1996), the female swishing her tail vigorously to mix the eggs and sperm and distribute the fertilized eggs. The adhesive eggs stick to submerged vegetation and hatch in 20–60 hours, depending on temperature. The yolk sac is absorbed within 3–4 days (de Graaf and Janssen 1996) and the stomach is fully functional within 5–6 days after onset of exogenous feeding (Hecht 1996). Sexual differentiation begins between 10 and 15 days after hatching (Legendre and Jalabert 1988). The female is the heterogametic sex (Volckaert and Agnèse 1996). Larvae feed and grow rapidly in the warm, nutrient-rich floodplain, reaching a size of 3–7 g within 30 days. As flooded marginal areas dry up with the end of the rains, juveniles and adults make their way back to deeper water. In areas with two rainy seasons, there are usually two reproductive peaks during the year, corresponding in intensity to the magnitude of the rains.

CULTURED CLARIIDS

The main culture species at present are *C. gariepinus* (by far the most widely cultured) and to a lesser degree, *C. anguillaris* and *C. ngamensis* in Africa and *C. batrachus, C. fuscus* and *C. macrocephalus* in Asia, with a few others bred for the aquarium trade, most notably the Namibian endemic blind cave catfish, *C. cavernicola*.

The only two members of the subgenus Clarias, *C. anguillaris* and *C. gariepinus*, are very similar (Volckaert et al. 1995; Rognon et al. 1998; Teugels 1998; Teugels 2003). Agnèse et al. (1997) found some evidence that *C. anguillaris* and *C. gariepinus* in the Senegal River hybridize naturally under certain conditions. Possibly due to the relatively restricted natural distribution of *C. anguillaris* in the Nile and West Africa, *C. gariepinus* is the more widely studied and cultured of the two.

C. ngamensis is native to southern Africa. Unlike other *Clarias* species, it has a very short adipose fin and may be transitional between *Clarias* and *Heterobranchus* (Skelton 1993).

In addition to the genus *Clarias*, there are three other Clariidae genera that are of at least some potential interest and have been tested in aquaculture. The endemic *Bathyclarias* (*Bathyclarias atribranchus, B. euryodon, B. filicibarbis, B. foveolatus, B. gigas, B. ilesi, B. jacksoni, B. longibarbis, B. loweae, B. nyasensis. B. rotundifrons, B.*

worthingtoni) species flock in Lake Malawi, range in size from 60 to 135 cm, and have been tried in ponds (Msiska et al. 1991).

Gymnallabes typus, native to the lower course and delta of the Niger River and Cross River basin in Nigeria and Cameroon, has been tested as an alternative to eels in trials in the Netherlands (Teugels and Gourène 1998).

Reaching over 1 m in length and 55 kg in weight (Skelton 1993), the non-*Clarias* Clariid that has received the most attention by fishfarmers and is actually produced in a number of African countries, is *Heterobranchus longifilis*. Otémé et al. (1996) report that, under optimum conditions, *H. longifilis* grows twice as fast as *C. gariepinus*. This species, known as vundu in southern Africa, is found throughout Africa in the Nile, Niger, Senegal, Congo, Gambia, Benué, Volta and Zambezi River systems as well as all the coastal basins from Guinea to Nigeria, and in Lakes Tanganyika, Edward and Chad. Of particular interest has been the hybrid between *H. longifilis* ♀ and *C. gariepinus* ♂ first produced in South Africa and commonly known as the "heteroclarias".

GENETIC DIVERSITY IN CULTURED STOCKS

As with other cultured species, domestication or captive holding on fishfarms has resulted in a certain amount of genetic change, usually deterioration. Da Costa (1998) found a 20% difference between cultured and wild stocks of *C. anguillaris*, with the cultured stock performing significantly worse. Otémé (1998) and Agnèse et al. (1995) found that a population of *H. longifilis* held for four generations on a government research station had reduced genetic variability, lower fry growth rate and survival, higher levels of fry deformity, and greater variability in larval growth rate. Van der Bank (1998) found that mean heterozygosity in a captive population (0.3%) of *C. gariepinus* was an order of magnitude less than in a wild population (5%). Hoffman et al. (1995) found that wild *C. gariepinus* grew 15–43% better under culture conditions than populations that had been held on-farm. Van der Walt et al. (1993a) reviewed genetic variability in *C. gariepinus* and found strong evidence of inbreeding, founder effects and genetic drift in most captive populations.

Good genetic management can reverse many of these negative consequences of domestication and even improve performance. Van der Bank et al. (1992) and Grobler et al. (1997) showed that outcrossing to other captive stocks and with wild fish raised mean heterozygosity of a farmed population to 7.6% compared to 5% in a wild stock. Similarly, Teugels et al. (1992) found that populations of *C. gariepinus* that were purposefully outcrossed among research stations were significantly more heterozygous than fish held in isolation on a single station. Among *C. gariepinus* stocks, significant variation in growth indicates that selection for better performance in aquaculture is possible (Van der Bank 1998). Van der Walt et al. (1993b) showed that a well-maintained experimental line of *C. gariepinus* outperformed wild strains and a population held on a local hatchery. De Matos Martins et al. (2005) documented significant variation in growth among juvenile *C. gariepinus*, implying that selection is possible.

Although two wild populations of *C. macrocephalus* and one of *C. batrachus* in Malaysia showed very low genetic variability (Daoud et al. 1989), and response to mass selection for resistance to *Aeromonas hydrophila* in *C. macrocephalus* in early trials in Thailand showed little gain (Uraiwan 1993; na-Nakorn et al. 1994), Thai researchers have a selected line of *C. macrocephalus* that grows 12% better than control lines.

In Southeast Asia, hybrids between *C. gariepinus* and *C. batrachus* or *C. macrocephalus* have been widely produced, reportedly combining the faster growth of the African catfish with the more appealing culinary attributes of those from Asia (Uraiwan 1993).

CONSERVATION STATUS

Most members of the genus *Clarias* are under no particular danger of extinction at present. Four species, all African, appear on the IUCN Red List of Threatened

Species (2007): *C. alluadi, C. cavernicola, C. maclerni* and *C. werneri*. The closely related, and easily confused, *C. alluadi* and *C. werneri* (Seegers 1996) are considered as of Least Concern, with widespread distributions and no particular threats. *C. cavernicola* and *C. maclerni* are considered as Critically Endangered. *C. cavernicola* is endangered due to the fact that its entire range is one pool of 45 m^2 in the Aigamas cave, Namibia, and the water level is going down due to groundwater extraction in the area. *C. maclareni*, while under no specific threat, occupies one lake, Barombi-M'bo, on the slopes of Mt. Cameroon, an active volcano.

Although *Clarias* species are generally quite hardy, Mohamed et al. (1999) found that sections of the Nile River which received heavy levels of industrial pollution contained significantly fewer *C. gariepinus* than other sections and attributed this to poor water quality. As they are originally best adapted to swamp forest habitats, *Clarias* species worldwide have come under increasing pressure as forests become increasingly fragmented (Sudarto 2007).

Interactions between farmed lines of *Clarias* and wild populations may represent a significant threat to the genetic integrity of the latter. There appears to be a significant amount of genetic differentiation across the distribution of *C. gariepinus*, with populations in West/Central Africa differing morphometrically (width of premaxillary toothplate, length of occipital process and dorsal fin length) from those in eastern and southern Africa (Teugels 1998), possibly reflected in earlier taxonomic recognition of three species, two of which *C. mossambicus* and *C. lazera*, have since been incorporated into *C. gariepinus*. Transcontinental movement of populations used for aquaculture may pose a threat to this differentiation.

In Africa, the *H. longifilis* x *C. gariepinus* hybrid, once thought to be sterile, has been recently shown to have the capacity to interbreed with wild *C. gariepinus*, creating what is effectively a transgenic Clariid, with unpredictable consequences for the wild populations, but quite possibly including a reduction in overall fecundity and therefore fitness leading to reductions in the wild stock (T. Hecht, pers. comm., 2005). Euzet and Pariselle (1996) found that "heteroclarias" juveniles were susceptible to *Henneguya* infections to which both pure *Heterobranchus* and *Clarias* were immune, raising further questions about the wisdom of creating this hybrid.

In Asia, the widely produced *C. macrocephalus* ♀ and *C. gariepinus* ♂ hybrid has been escaping from fishfarms and interbreeding with wild *Clarias* spp. for many years, causing widespread concern about the effects of the introgression of *C. gariepinus* genes into the local species, lowering what is widely perceived to be their better qualities as tablefish, and consequently the economic value of the wild catch and the future value of wild genetic material in aquaculture applications. In Thailand, the introduction and escape from aquaculture of the *C. macrocephalus* x *C. gariepinus* hybrid has been related to the declines in wild stocks of *C. batrachus*. Conversely, escape of *C. batrachus* from culture facilities has been linked to the virtual disappearance of wild *C. macrocephalus* in the Philippines (Main and Reynolds 1993; Lever 1996); likewise in Taiwan, where *C. batrachus* has interbred with the indigenous *C. fuscus*, which is now in serious decline as a pure species (Lever 1996).

In addition to the dangers posed to indigenous biodiversity by these interspecific and intergeneric hybrids, concerns have been expressed about the possible negative consequences of escapees from monogenetic but domesticated culture populations reducing the fitness of conspecific wild populations. The magnitude of this threat is proportional to the genetic distance between wild and captive populations. If the difference is extreme, introgression of domesticated genomes into what is theoretically defined as a perfectly fit wild population, unavoidably reduces the purity of the wild genome. Whether such a change in gene frequencies represents a real threat to survival is unknown. Both in the wild and in captivity, shifting gene frequencies are a natural consequence of any significant change in the environment.

In cases where important or rare *Clarias* biodiversity may come under such a threat, every effort should be made to assess the actual risks prior to introducing cultured populations to a new area.

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ANNEX A

Clarias species, natural distribution, maximum reported size and status as an aquaculture species (FishBase 2007).

Species	Natural distribution	Maximum reported	Culture?
Clarias abbreviatus	Asia: Macau		No
Clarias agboyiensis	Africa: Ofin and Volta systems, Ghana; coastal rivers, Togo; Ouémé River, Benin; Ogun and Oshun rivers, Niger delta; coastal rivers (especially Cross River), Nigeria.	29 cm/178 g	No
Clarias albopunctatus	Africa: Lake Chad, upper Benué system, central Congo system.	19.5 cm	No
Clarias alluaudi	Africa: Lakes Victoria, Kyoga, Edward, Rukwa and Tanganyika.	35 cm	No
Clarias anfractus	Asia: Borneo, Malaysia.	17.6 cm	No
Clarias angolensis	Africa: Lower and Central Congo system.	35 cm	Aquaria
Clarias anguillaris	Africa: Nile; Lake Chad system including Logone and Shari rivers; Niger and Benoué systems; coastal rivers in Benin, Togo, Ghana and Côte d'Ivoire; Gambia and Senegal and Volta systems; relict populations in Mauritania and Algeria.	1 m/7 kg	Experi- mental
Clarias batrachu	Asia: Mekong and Chao Phraya basins, Malay Peninsula, Sumatra, Java, Borneo, Sri Lanka (?)	47 cm/1.2 kg	Yes
Clarias batu	Asia: endemic to Pulau Tioman, Malaysia.	30.5 cm	No
Clarias brachysoma	Asia: endemic to Sri Lanka.	50 cm/3.6 kg	Aquaria
Clarias buettikoferi	Africa: Upper Gambia to the Agnebi River in Côte d'Ivoire. Ghana (?)	19.2 cm	No
Clarias buthupogon	Africa: Congo system, Ogowe, Sanaga, Wouri, Cross and coastal rivers of Nigeria and Benin. Luongo River, Zambia (?)	90 cm	No
Clarias camerunensis	Africa: coastal rivers Togo to the lower and central Congo system. Ghana (?)	46.6 cm	No
Clarias cataractus	Asia: Malay Peninsula.		
Clarias cavernicola	Africa: Aigumas Cave, North Otavi, Namibia.	16.1 cm	Aquaria
Clarias dayi	Asia: Wynaad Hills, Western Ghats of Kerala, India. Ombatta, Mudumalai, Tamil Nadu (?)	17.5 cm	No
Clarias dhonti	Africa: Niemba and Koki rivers, west of Lake Tanganyika (DR Congo).	18.5 cm	No
Clarias dumerilii	Africa: Central and Upper Congo and Luapula systems.	30.5 cm	No
Clarias dussumieri	Asia: Goa, Karnataka, Kerala and Pondicherry in India.	25 cm	No
Clarias ebriensis	Africa: Côte d'Ivoire to southeast Nigeria.	31.5 cm/240 g	No
Clarias engelseni	Africa: Yei River, Sudan.	18.5 cm	No
Clarias fuscus	Asia: China, Taiwan, Philippines, Viet Nam and Oceania: Hawaii	24.5 cm	Yes
Clarias gabonensis	Africa: Lower and Middle Congo system, including Lake Tumba and Pool Malebo; Chiloango and Ogowe River systems.	36 cm	No
*Clarias gariepinus**	Africa: almost Pan-Africa; absent from Maghreb, upper and lower Guinea, Cape and probably Nogal provinces. Asia: Jordan, Israel, Lebanon, Syria and Turkey. Widely introduced to other parts of Africa, Europe and Asia.	1.7 m/60 kg	Yes
Clarias hilli	Africa: Middle Congo and Lake Albert.	19.6 cm	No
Clarias insolitus	Asia: upper Barito River drainage in southern Borneo, Indonesia.	14 cm	No
Clarias intermedius	Asia: Indonesia.		No
Clarias jaensis	Africa: Ogowé River, Gabon; Sanaga, Nyong, Kribi, Ntem, Dja, Sangha rivers, Cameroon and southeast Nigeria.	48.3 cm	No
Clarias kapuasensis	Asia: West Borneo, Indonesia.	26 cm	No
Clarias laeviceps dialonensis	Africa: Fouta Dialon (Guinea) and coastal rivers, Sierra Leone.	25.7 cm	No
Clarias laeviceps laeviceps	Africa: Saint Paul River, Liberia eastward to the Volta system.	31.7 cm	No
Clarias lamottei	Africa: Nzi River, Bandama system, Côte d'Ivoire.	16.4 cm	No
Clarias leiacanthus	Asia: Indonesia.	33 cm	No
Clarias liocephalus	Africa: Lakes Victoria, Edward, George, Kivu, Tanganyika, Malawi, small lakes of Uganda, smaller lakes of Rwanda, Bangweulu-Moero, Kagera, Malagarazi, Ruzizi, Tana, Cunene, Okavango, upper Zambezi and Kafue River systems + Zambian Congo.	32 cm	No
Clarias longior	Africa: Kribi, Lobi and Ntem rivers in south Cameroon.	22.5 cm	No
Clarias maclareni	Africa: endemic to Lake Barombi-Mbo, NW Cameroon.	36 cm	No

Clarias species, natural distribution, ... cont'd.

Species	Natural distribution	Maximum reported	Culture?
Clarias macrocephalus	Asia: Thailand to Viet Nam. Introduced to China, Malaysia, Guam and Philippines.	1.2 m	Yes
Clarias macromystax	Africa: Oueme River, Benin; Ogun and Oshun systems, Nigeria; Niger delta + Niger up to Lake Kainji and Benue River (Nigeria).	31.6 cm	No
Clarias meladerma	Asia: Mekong to Indonesia and Philippines.	35 cm	No
Clarias microstomus	Asia: Mahakam and Kayan river drainages in east Borneo.	14.1 cm	No
Clarias nebulosus	Asia: Sri Lanka.		No
Clarias ngamensis	Africa: Quanza, Cunene, Okavango, Chobe, Pungwe, Buzi, Save, Limpopo, Incomati, lower Pongolo, lower Sabi, Lundi, Kafue, upper Lualaba, Luapula, Zambian Congo, lower Shire and upper Zambezi (above Victoria Falls) river systems. Lakes Ngami, Malawi, Moero and Bangweulu.	73 cm/4 kg	Experi-mental
Clarias nieuhofii	Asia: Southeast Asia.	50 cm	No
Clarias nigricans	Asia: Mahakam drainage, Borneo, Indonesia.	30.8 cm	No
Clarias nigromarmoratus	Africa: central Congo system in Angola.	17.6 cm	No
Clarias olivaceus	Asia: Padang, Sumatra, Indonesia.	24.2 cm	No
Clarias pachynema	Africa: coastal rivers of south Cameroon (up to Sanaga River); Ogowe system, Gabon and Middle Congo system.	35.6 cm	No
Clarias planiceps	Asia: Belakin area, Ulu Sungai Anap, Sarawak, Malaysia	29.7 cm	No
Clarias platycephalus	Africa: lower and central Congo basin, Lower Ntem River Basin (?)	37.6 cm	No
Clarias pseudoleiacanthus	Asia: Borneo, Indonesia.	24.5 cm	No
Clarias pseudonieuhofii	Asia: Borneo	31.6 cm	No
Clarias salae	Africa: Konkoure system (Guinea) to the Cavally River (Côte d'Ivoire).	50.8 cm	No
Clarias stappersii	Africa: Luapula-Moero, Kafue, upper Zambezi, Cunene, Okavango; Zambian and Kasaï Congo river systems.	41 cm	No
Clarias submarginatus	Africa: Kribi and Lobi rivers (south Cameroon) + Luongo and Congo systems, Zambia.	16 cm	No
Clarias sulcatus	Asia: Malaysia.	20.7 cm	No
Clarias teijsmanni	Asia: Sundaland.	22 cm	No
Clarias theodorae	Africa: Zambezi, Kafue, Shire rivers; Upper Congo, Chobe, Okavango, Cunene, Pungwe, Sabi, Lundi, Zimbabwean tributaries of the Limpopo, Incomati, Pongolo and Umgeni rivers; Lakes Tanganyika, Bangweulu, Kobo, Niumbe, Mweru, Malawi, Sibaya.	35 cm	Aquaria
Clarias werneri	Africa: Lakes Victoria, Kyoga, Edward and Tanganyika. Bahr el Jebel, Sudan (?)	23 cm	No

* *C. gariepinus* populations from western and southern Africa exhibit a certain amount of genetic differentiation from each other, probably indicating that this nearly pan-African species has begun to differentiate since the climatological and geological events of the Miocene (~20 million years BP) isolated the once-contiguous populations (Rognon et al. 1998).

REPRODUCTIVE AND GROWOUT MANAGEMENT OF AFRICAN CATFISH IN THE NETHERLANDS

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INTRODUCTION

This paper describes two main areas of African catfish production: reproductive and growout management. The technical aspects of the paper are viewed from the perspective of a producer with many years of practical experience in fingerling production in a European environment. The company is named Fleuren and Nooijen Fishfarms Ltd., based in the Netherlands. Its activities also include design and construction of recirculation aquaculture systems (RAS) for a range of fish species (catfish, tilapia, ornamental fish), trading for aquaculture necessities and consultancy.

SELECTION, HYBRIDIZATION AND MAINTENANCE OF BROODSTOCK

For many farmers broodstock management is rarely paid due attention. Fish farmers or producers mainly focus on availability and price of fingerlings. A formal breeding program to improve broodstock does not exist in many countries. Scientific research on genetics of African catfish is limited and is not well applied in practice. By far, mass selection within families is often practised. Growth is the main criterion in selection although other traits, such as efficiency of food use or survival, are also considered. In the particular context of Europe, dressing percentage and meat quality emerge as economically important traits.

At Fleuren and Nooijen Fishfarms Ltd., the mass selection program in African catfish has been carried out for several generations. The pure *Clarias gariepinus* has been widely cultured in the Netherlands. In addition, the elite parents from this program are used to cross with *Heterobranchus longifilis* to produce fry or fingerling hybrid as a final product for commercial purposes. The hybrid is named *Heteroclarias*. They cannot be used for reproduction by customers. They also have other growing advantages, such as higher dressing yield and niche market product for better price. However, the hybrid exhibited aggressive behavior and large variation in body weight. Although this scheme has been working quite well, there are also problems with the selection of broodstock. It is impossible to know the exact identity of the fish. There is no way to control or restrict inbreeding accumulation. The level of genetic variation in the population is also not monitored or estimated.

Besides selection, the maintenance of broodstock is another important component for catfish production. Efficient use of breeders saves expenses and labor. Necessities for good broodstock maintenance include development of traceability methods (e.g., electronic tagging), optimization of husbandry systems, and appropriate feeding regime and nutrition.

REPRODUCTION

The productivity of females generally depends on weight, age, spawning frequency and management (water quality, feed, feeding, stress) of individuals. The relative fecundity of females is approximately 5–12% of their body weight. On average, there are about 500 eggs per gram of body weight in the fish population of Fleuren and Nooijen Fishfarms. The egg size increases with weight and age of the females. Experience shows that use of females should start when they exceed 1.5 years of age. Induction of hormones using human chorionic gonadotropin (HCG) or catfish pituitaries should be applied to ripen and mature fish. Maturation time depends on temperature. Around 25 °C is optimal. Determining the optimal time for stripping is critical—too early or too late may have negative effect on hatching rate.

Sperm production in males is always present without hormone induction. Stripping the males still remains impossible due to the physiology of the testis. Males are often sacrificed as they undergo an operation to remove sperm. Fresh sperm can be preserved in 0.9% saline solution in a refrigerator (4 °C) for a maximum of 24 hours. For cryopreservation and conservation purposes, sperm (not embryo) can be stored in a cryoprotectant agent in liquid nitrogen (-173 °C). Important genetic materials should be cryoconserved for future need. Until now, methods of cryopreservation for practical use in catfish hatcheries have not been available.

The procedure of artificial fertilization in African catfish is quite simple. Eggs and sperm are first collected in dry porcelain or glass bowls. Often, 0.25 ml sperm is added to 100 g of eggs. Then 100–200 ml water is mixed and gently stirred for 1 minute. Also, note that no sperm-life extenders are used.

HATCHERY MANAGEMENT BASED ON RECIRCULATION AQUACULTURE SYSTEMS

Successful hatcheries are very profitable. The success rates of hatcheries vary enormously, ranging from 5 to 200 eggs to grow one juvenile. Indoor recirculation systems (RAS) are widely used in Europe (especially the Netherlands) to culture African catfish, although other systems also exist such as ponds or flow-through.

The basic principles of RAS include removal of solid particles, spilled feed, dissolved organic matter and CO_2, conversion of ammonium into the less harmful nitrate (nitrification) or conversion of nitrate into N_2 gas (denitrification). The general design features and a schematic overview of RAS are illustrated in Figures 1 and 2, respectively.

The use of RAS in hatcheries, however, has both advantages and disadvantages. The advantages of RAS include better control of environment and diseases. Feeding efficiency of RAS is high. There is no predation. It is also easy to grade, take care and harvest the fish. RAS needs

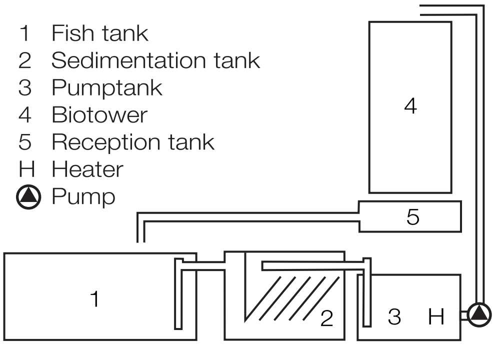

Figure 1: General design features of RAS

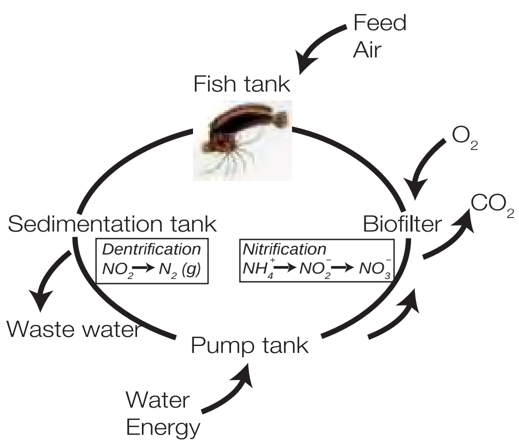

Figure 2: Schematic overview of RAS

limited space for installation. A bore hole is used as the only water source. On the other hand, RAS also requires intensive capital investment, high-quality infrastructure, and high running costs and feed quality.

Overall, the sections in a hatchery, based on RAS, are designed specifically for broodstock, incubation, and advanced fry and juvenile. The specific life stages of African catfish in RAS are shown in Table 1. Technical specifications (e.g., system, tank material and size) and management parameters (e.g., stocking density, feeding, light regime, production cycle and water source) required for broodstock, incubation, and advanced fry and juvenile are respectively given in Tables 2, 3, 4 and 5.

Feeds and feeding are critical factors for profitable farming of African catfish based on RAS. Different types of feeds are required for larvae, advanced fry, juvenile

Table 1: Feed and water quality parameters required for different rearing stages of African catfish

Growth phase	Age (weeks)	Weight	System	Feed	Optimal water quality parameters NH_4	NO_2	pH	Temp. (°C)
Fry – larvae	0–2	0.05–0.1 g	Incubation system	Dry diet 0.2–0.3 mm	<3	<1	7	28
Fingerling	3–5	0.1–1.0 g	Advanced fry system	Dry diet 0.3–0.8 mm	<4	<2	7	28
Juvenile	5–8	1.0–8 g	Juvenile culture system	Dry diet 0.8–1.5 mm	<10	<2	7	28
Broodstock	>–1,5 year	> 4 kg	Broodstock system	Broodstock diet 9 mm	<20	<3	7	25

Table 2: Broodstock

System	RAS or flow-through – continuous
Tank material	Concrete, glass fiber or plastic
Tank size	1,200–5,000 l
Stocking density	Maximum of 75 kg/m^3
Production cycle	180–1,500 days
Feeding regime	Ad lib – less than 0.5% BW/day
Light regime	12 L –12 D
Water source	Bore hole
Mode of cleaning	Draining components of system
Number of broodstock for 1 million fry	25 pairs

Table 3: Incubation

System	RAS – all in, all out
Tank material	Plastic or glass
Tank size	100–1,000 l
Stocking density	Maximum of 600 g/m^3
Production cycle	0–14 days
Survival	40%
Feeding regime	10–8% BW/day
Light regime	0–3 days 24 L; 4–14 days low light intensity
Water source	Bore hole
Mode of cleaning	Disinfection of all components of system between each cycle

Table 4: Advanced fry

System	RAS – all in, all out
Tank material	Plastic or glass
Tank size	600–1,000 l
Stocking density	Maximum of 10,000 pc/m^3
Production cycle	14–40 days
Survival rate	58%
Feeding regime	8–6% BW/day
Light regime	Low light intensity
Water source	Bore hole
Mode of cleaning	Disinfection of all components of system between each cycle

Table 5: Juvenile

System	RAS or green water tank/pond system – all in, all out
Tank material	Plastic, glass fiber or concrete
Tank size	600–5,000 l
Stocking density	RAS: maximum of 6,000 pc/m^3 Green water: maximum of 400 pc/m^3
Production cycle	40–61 days
Survival rate	75%
Feeding regime	6–5% BW/day
Light regime	Low light intensity
Water source	Bore hole or open water
Mode of cleaning	Cleaning of all components of system between each cycle

and brooders. With high-quality extruded feed, the fish can perform fast growth, low food conversion ratio (FCR), high survival rate and low deformities. The economics of fry, advanced fry and juvenile feeding is given in Table 6, which indicates that buying good quality feed is not expensive.

Grading during early stages of rearing is essential for African catfish because this is a carnivorous species displaying cannibalism from the fry stage. Cannibalism is the main cause of high mortality in hatcheries. Suboptimal (or poor) rearing conditions also induce development of shooters. Grading should be carried out once or twice during advanced fry stage and once during juvenile stage.

Another issue with RAS is maintenance and management. Without proper maintenance, problems can arise gradually in initial stages and can become serious later. For technical aspects, it is necessary to monitor water parameters regularly by periodic flushing, cleaning and disinfection. There should be a pest control program, maintenance of infrastructure, repair of farm equipment, presence of spare parts, cleaning of environment and proper record keeping of the whole production process.

DISEASES

Diseases are related to rearing environments and management practices. Curing with medicine is a symptomatic solution only. The cause of any disease should be identified at the farm level. Threats for African catfish include toxins (CO_2, NO_2, NH_4, chemicals), element deficiencies, overfeeding, parasites, bacteria and viruses. When the fish suffer from toxins, they show signs of hanging, brown blood, quick mass mortality, increase or decrease of slime and nervous behavior. Treatment in these cases includes flushing, salt application and ventilation. Generally, farmers don't pay good attention to deficiencies in vitamin, minerals, fatty or amino acids. In severe cases, the fish can stop feeding and growing or can show sluggish behavior and deformities (e.g., broken heads). Immediate reaction includes feed improvement and better feed storage.

Table 6: Economics of fry, advanced fry and juvenile feeding

Fry	**Production 100,000 fry of 0.1 g** FCR 0.6 Survival 40%			
	Feed	**Quantity**	***Price/kg**	**Total**
	Artemia	2 kg	€ 55	€ 110
	0.2–0.3 mm dry feed	7.2 kg	€ 20	€ 144
			Total	€ 254
			Price per fry	€ 0.003
Advanced fry	**Production 100,000 advanced fry of 1 g** FCR 0.6 Survival 58%			
	Feed	**Quantity**	**Price/kg**	**Total**
	0.3–0.5 mm and 0.5–0.8 mm dry feed	65 kg	€ 4	€ 260
	`		Total	€ 260
			Price per advanced fry	€ 0.003
Juvenile	**Production 100,000 juveniles of 8.0 g** FCR 0.7 Survival 75%			
	Feed	**Quantity**	**Price/kg**	**Total**
	0.8–1.2 mm and 1.2–1.5 mm dry feed	550 kg	€ 3	€ 1.650
			Total	€ 1.650
			Price per juvenile	€ 0.02

* Prices are indicative only and based on 2007 data; €1.0 equivalent to US$1.33 January 2007; €1.0 equivalent to US$1.46 December 2007.

Overfeeding is not recommended because the digestive system of the fish cannot cope with the feeding level or method. Typical symptoms of overfed fish include open bellies, sluggish behavior, hanging or mortality. For parasites, there are gill and skin worms or flagellates. The fish show abnormal signs such as cotton-like spots on body, inactive or sluggish behavior, increase of slime and nervous behavior. Under these situations, salt treatment and increase of water temperature are needed. There are two main bacterial diseases: aeromonas and citrobacter-related origins. The fish show symptoms such as ulcers on skin, necrosis of barbles, inactive feeding, sluggish behavior, hanging, and limited to severe mortality. They should be treated using antibiotics along with sterilization of the environment and improvement of management practices. By far, virus-related diseases are not reported in African catfish. It is wise to observe the fish closely and immediately identify abnormal behavior. Problems always have multiple causes. To distinguish the primary cause and its solution is not easy. A good farmer should identify problems before they occur.

HARVEST AND TRANSPORT OF FRY AND JUVENILE

Depending on the size of the catfish, advanced fry and juveniles should not be fed 12–18 hours prior to harvesting. A thorough inspection is needed to see if the fish is healthy for selling. The fish should not be disseminated if recent treatments have taken place. Shooters should be taken out with grader. Counting the number of fish can be based on the average weight method. Harvesting should be done without disturbance. Customers and their transport tanks are never allowed in the farm when harvesting. Customers are always given 2% overweight and are advised about the last feeding level. Responsibility stops at the farm gate. Advanced fry should be packed in a polyethylene bag with one-third water and two-third oxygen. Juveniles can be in open containers. Stocking density depends on duration of transport, water temperature, oxygen or air supply, and condition of fish.

THOUGHTS ABOUT CATFISH DEVELOPMENT AND PRODUCTION IN AFRICA

HATCHERY

There is great potential to establish catfish hatcheries with various scales of production in African countries. Medium to large hatcheries are able to pay for the infrastructure and technological innovation. They would become centers of knowledge and experience for other farmers. A network of hatcheries should be spread over the regions to limit transport. The development of a commercially driven catfish industry is important to ensure that hatcheries can continuously produce adequate and high-quality seed to supply local farmers and producers.

GROWOUT SYSTEMS

The choice of growout systems generally depends on climate, location, level of development of regions or countries, and

Table 7: Characteristics of different farming systems for African catfish

Pond	Flow-through	RAS
Dependence on land, geology, soil composition	Semidependence on land	Nondependence on land
High water consumption (1 m^3/kg fish), surface water	Water source, surface water or bore hole (0.4 m^3/kg)	Water source, bore hole (0.15 m^3/kg), purification
Extensive farming: 10–15 kg/m^3	Semi-intensive farming (75–100 kg/m^3)	Intensive farming (700–1,000 kg/m^3)
Cropping of large volume of fish	Small crops	Small and regular crops
Stagnant waterbody with irregular flushing	Concrete tanks or small ponds with regular flushing	Indoor system, concrete or glass fiber tanks

scale of production. For catfish, there are three main production systems: (1) pond, (2) flow-through and (3) indoor recirculation. Each system has its own characteristics and management needs (Table 7). A relative comparison among these systems (pond, flow-through and recirculation) is presented in Table 8.

FEEDS

The African catfish is a carnivorous fish which grows best on animal-based diets. The availability of animal proteins and fats for use in fishfeed in developing countries is poor. Farmers can use locally produced compounded feeds, imported feeds, on-farm moist pellets or trash products (e.g., chicken waste, maggots). The choice of feed depends on the production system used. Feed often make up 70–85% of production cost. Thus feed management (feeding, feed storage and feed selection) is crucial for success.

For other technical issues in regard to grading, harvesting, hatchery maintenance and management, the same procedures or principles can be applied as described above.

To recapitulate, for the conditions of African countries, backyard farming is accessible to many small farmers and is an excellent tool for poverty eradication. For medium to large-scale investors in aquaculture, pond farms can be very profitable. The RAS is only promising in industrial areas with perfect infrastructure and utilities. Feed and seed production, quality and availability should be improved to make catfish farming more successful in future.

Table 8: Advantages and disadvantages of pond, flow-through and RAS

Criteria	Pond	Flow-through	Recirculation
Infrastructure	Low	Moderate	Perfect
Investments	Low	Moderate	High
Running costs	Low	Moderate	High
Labor	Less demanding	Average	High and skilled
Feed	Flexible	Good quality	High quality (extruded feed)
Location	Rural areas	Rural or urban	Urban
Water use	High	High	Efficient
Environment	Uncontrolled	Polluted	Controlled

CATFISH NUTRITION — ASPECTS TO CONSIDER

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The cost of feed usually constitutes the major expense in the culture of fish, comprising about 50% of the running costs. Therefore, any saving in the cost of feed would have a considerable impact on the profitability of production.

There is no doubt that using high-quality feed will lead to better growth and production results. Table 1 illustrates the advantages of high-quality feeds over and above the direct growth response of the fish. Low digestibility of the feed will also cause water contamination and be detrimental to fish growth.

Unlike other farmed animals, fish require a high level of protein in their diet and protein is one of the most expensive dietary components. Fish need a high supply of protein because they use it as a source of energy. Among the fish, carnivores typically require higher levels of protein than herbivores. The African catfish, although defined as an omnivore is more carnivorous in nature and thus requires relatively high levels of protein, and fat.

The gross dietary protein requirement of African catfish is in the region of 40%. Table 2 shows the proximate minimum dietary requirements for catfish during the growout phase. The best growth rates and feed conversion ratio (FCR) are achieved with a diet containing between 38% and 42% crude protein and an energy level of 12 kJ/g. To date, the specific requirements of the African catfish for essential amino acids, essential fatty acids, vitamins and minerals have not yet been determined. Most formulations use the levels determined for the channel catfish (*Ictalurus punctatus*). Table 2 shows the approximate minimum requirements for this fish.

There are a number of methods that can be employed to increase food use and thus reduce production costs. Among these are the use of chemo-attractants and increasing the digestibility of food through enhancement of digestive enzyme activity.

Fish (including catfish) use chemoreception to locate and consume their food. Replacement of fishmeal with plantmeal in the diets of fish might lead to problems in locating and consuming the feed. The use of various chemoattractants such as specific amino acids (see Figure 1) or betaine can alleviate this problem as well as enhance food consumption. For the same reason, it is also important to know that when the fish are under stress they secrete mucus that can cover their chemoreceptors and hinder their ability to locate and consume the food.

Table 1: Comparison of high- versus low-quality feed for catfish

Type of feed	High quality	Low quality
% Protein	35-40%	7-20%
Price (approx. US$)	1 per kg	0.5 per kg
Feed conversion ratio (FCR)	1 : 1.0-1.2	1 : 2.0-2.5
Growth rate to market size	5-6 months	12-14 months
Water contamination	Low	High
Profitability	High	Low

Table 2: Approximate minimum dietary requirements for catfish

Feed ingredient	% inclusion
Digestible energy	12 kJ/g
Crude protein level	40
Total lipid	11
Calcium	1.5
Phosphorus	0.7

Increasing the activity of the intestinal enzymes can be achieved by the addition of low levels of alcohol or salt to the diet (as has been demonstrated by Harpaz et al. 1994, 2005). The salt (NaCl) is also helpful in the absorption of the digested food since this activity is dependent on the Na/K ATPase pump that operates better when Na^+ ions are present in the intestine. This method can be used for both juvenile and growout stages of production in which feed expenses are highest.

From the age of 1.5 months, the dietary requirements of African catfish do not seem to change although the feeding level does need to be adjusted. At the optimal temperature for growth (28°C) the ration size decreases with increasing body size (Table 3). As the fish grow larger, their relative consumption rates decrease from approximately 10% of body weight (BW)/day (at the age of 1 month) to around 3-4% of BW/day (at the age of 3 months and above). During the growout phase, the fish should be fed at least twice a day and if possible three times a day, the quantity administered during the first feeding larger than the rest. The feeding level should be adjusted according to the recommended daily ration table (Table 3) which takes into account both rearing temperature and fish size. Providing a number of meals per day and spreading the food (as opposed to one feeding point) will lead to a decrease in the size variability of the fish.

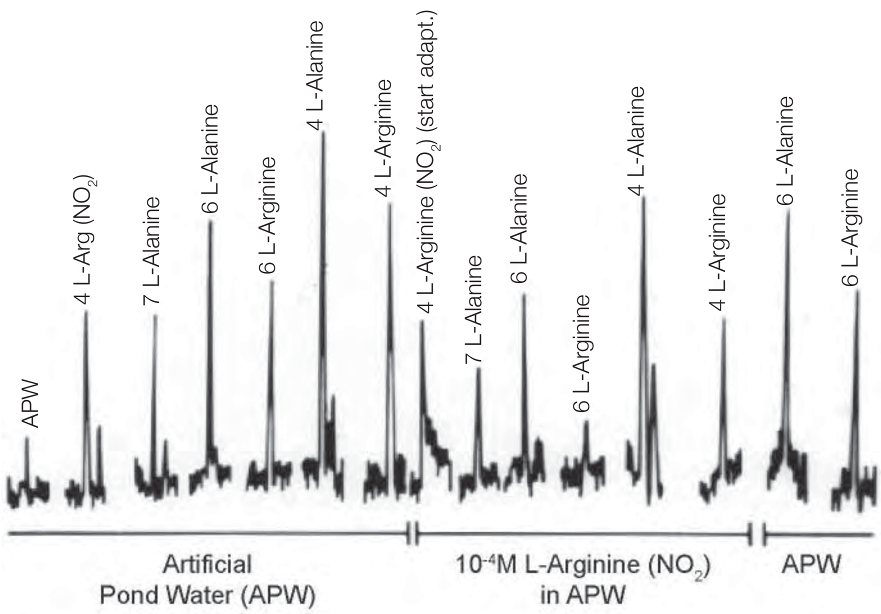

Figure 1: Integrated neural responses recorded from catfish barbels following exposure to two chemo-attractants (alanine and arginine) at concentrations of 10^{-4}–10^{-7}M

Table 3: Recommended daily rations for the African catfish, at different temperatures and fish sizes. Feeding values (in % BW/day) based on body weight and temperature.

Temp. (°C)	Fish size (g) 1-10	11-25	26-50	51-100	101-300	301-800
16	1.0	0.6	0.4	0.3	0.2	0.2
18	3.0	1.6	1.0	0.8	0.6	0.5
20	5.0	3.0	2.0	1.5	1.2	1.0
22	6.8	4.5	3.0	2.4	2.0	1.7
24	8.1	6.0	4.0	3.0	2.5	2.2
26	9.5	6.6	5.1	3.6	3.2	2.8
28	10.0	7.0	5.5	4.0	3.5	3.1
30	9.8	6.8	5.3	3.7	3.2	2.9
32	9.5	6.5	5.0	3.5	3.0	2.8

Least-cost diets for *C. gariepinus* are based on computer-assisted formulations which take into account the price of different feed ingredients with a known nutritional composition, the nutritional requirements of the fish and the cheapest combination to achieve maximal growth. In order to succeed in this task, we need to know the nutritional value of the different ingredients and their digestibility by the fish. Research has revealed digestible energy values of various feed ingredients for *Clarias gariepinus*. This enables the creation of suitable feed formulations based on locally available ingredients. The results show that in catfish, the digestibility of plant-derived ingredients is usually much lower than that from animal sources. Thus it is important to use the above-mentioned methods to increase the activity of the digestive enzymes leading to better digestibility of the feeds.

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CLARIAS IN AQUACULTURE: PROS AND CONS

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In the past, there has been a lot of confusion about the motivations and justifications for aquaculture. Politicians have been in the driver's seat, taking it upon themselves to develop aquaculture as a means of meeting national food security targets. Low external input aquaculture (LEIA) technologies have been promoted to diversify and stabilize small-scale, artisanal farming systems with support from governments and international donors seeking to help the rural poor. In this approach, integrating new enterprises (e.g., aquaculture) into the farming system increases the efficiency of nutrient use and so improves the ecological performance of the entire farm. As a result of this approach, African aquaculture has remained within the domain of the subsistence farm and what expansion there has been over the last 30 years is mostly in terms of increasing numbers of small, low productivity ponds associated with a modest increase in fish production for household consumption. In general, fishfarming in Africa has done little or nothing in terms of major and lasting contributions to national food security and rural poverty alleviation.

Letting policy drive the development of the sector, has, if you will pardon the expression, muddied the water. Politicians do not, in general, grow fish and when they do, they seldom make any genuine profit. In fact, fishfarmers grow fish and if you ask them why they grow fish, they will not mention national food security or poverty alleviation. They will tell you that it is to make money.

So, this presentation is about how *Clarias* catfish can contribute to the profitability of aquaculture and the tools that I shall use to compare different models are based on principles of business planning, rather than social and/or ecological theory.

HASSLES = LOST MONEY

An important corollary of the LEIA model that has caused problems for fishfarmers is the importance that has been placed on ecological complexity as the primary means of increasing fishpond productivity. Complicated, knowledge-intensive integrated systems may look good on paper, but are often difficult to implement, particularly in Africa where nearly everything is a hassle. Because much of the cost associated with land, water, labor and depreciation are fixed, any time that a fishpond is dry, understocked, underfed or otherwise not being fully utilized due to the lack of some essential input, money is being lost. The more complicated a fishfarming system and the more elements that go into the basic production model, the more likely are farmers to encounter costly delays.

CASHFLOW VS. RETURN ON INVESTMENT

Another place where development planners have actually impeded progress is in the calculation of what is worth doing. Because development planners do not actually grow fish they tend to underestimate the difficulties associated with managing a fishfarm. In aquaculture, unlike all other types of animal husbandry and agriculture, the farmer cannot see what is being grown on the farm. Feed rates, size of the crop and harvest date are all approximate. This means that estimation from past experience, careful planning and close monitoring are essential for success. Profitable commercial fishfarming is generally a fulltime affair requiring patience, perseverance and good business sense. It is not for the disorganized or distracted.

Also, aquaculture is hard, often uncomfortable, work. Shoveling manure, mixing bloodmeal, pushing wheelbarrows full of dead fish over slippery pondbanks, getting up early in the morning, every morning, being wet and muddy, and late for dinner are just part of the game. To justify the amount of trouble that one unavoidably experiences in becoming a successful fishfarmer, at least in the early years, profits have to be significant and this implies a certain minimum scale of investment.

In Cameroon, detailed farming system analysis has shown that properly conducted LEIA can produce about 2,500 kg/ha of fish on inputs of locally available compost. This system costs the farmer very little, with cash outlays only for fingerlings. Labor is generally compensated with a portion of the harvest. These systems generate cash profits of between \$50 and \$300 per year (Table 1) on a total investment of \$360 and \$200 in recurrent costs (either cash or in-kind). With an attractive return on investment (ROI) of 40%, many development planners would view this as a successful intervention on farms that typically gross less than \$500 per year. However, considering that the farmer, instead of sitting under a tree drinking palm wine, had to dig and/or maintain a pond carved out of muddy, snake-infested forest and chop and haul about 4 t of compost materials over uneven terrain, these levels of return to management are generally considered inadequate even by poor farmers. The lack of enthusiasm among farmers is reflected by the inability of these small-scale enterprises to achieve sustainability, despite a number of development projects and startup subsidies provided by government.

Now consider a production system that *has* achieved sustainability (Table 2). Purchased inputs and paid labor are used to increase productivity up to 3,500 kg/ha. Improved management produces three crops per year instead of the one that can be grown on compost. Fish are grown to minimum market size and sold. Pond surface area is increased and total investment is now over \$5,000 with recurrent costs of about \$1,500. The ROI is reduced to 35%, but the return to management is now about \$2,000 on sales of 2 t of low-cost fish for low-income consumers. In addition, this farmer has created at least one new job by employing a worker, has paid other workers

Table 1: Enterprise budget (in Communaute Financiere Africaine franc [XAF]) for mixed-sex Nile tilapia LEIA production system stocked at 2 fish/m^2 and grown from 10 to 250 g in 360 days (US\$1 = XAF500)

	Number per cycle	**Unit price**	**Total cost**		**Amount (XAF)**	**Percentage of total**
Investment capital				**Amortization (years)**		
Pond construction (m^2)	500	0	0	10	0	0.00
Equipment			100,000	5	20,000	19.32
Stocking						
Fingerlings (number)	1,500	25	37,500		37,500	36.23
Operations						(44.44)
Feed (kg)	183.75	0	0		0	0.00
Labor (person 8-hour days)	4	1,500	6,000		6,000	5.80
Transport (return trips to market)	2	20,000	40,000		40,000	38.65
Total production costs (per cycle)					**103,500**	100.00
Revenues					**183,750**	Gross
Fish sales (kg)	123	1,500				
Productivity (kg/ha)	2,450				80,250	
			Total investment	**Financing (% per month)**		
			183,500	0	0	Interest
					80,250	Net per cycle
Cycles per year	1				**80,250**	**Net per year**
Total fish production per year (t)	**0.123**				**43.73**	**ROI**

to help dig the ponds and has generated significant revenues for the hatchery, feed manufacturer and retailers to whom the fish were sold. This scale of investment is what is known as a small and medium-scale enterprise (SME) and for the purposes of this paper will be the level at which comparisons are made.

THE SPECIFIC CASE OF *CLARIAS*

Having reviewed some basic concepts, let us now look at how *Clarias* catfish, mostly *gariepinus*, culture fits into the definition of a successful fishfarm. Catfish, particularly in West and Central Africa, command high market prices and demand among the growing and increasingly affluent population which is generally regarded as insatiable. In Cameroon for example, catfish of 300 g sell wholesale for over $4.00 per kilogram live on the pondbank, almost twice the price of tilapia. They also grow fast and are easy to feed, reaching a minimum market size of 350 g in 3 months or so, reaching nearly 1 kg in 1 year.

On the downside, catfish are relatively difficult to reproduce. Despite years of research that has established relatively simple and effective methods for induced spawning (and even controlled natural spawning in, for example, Egypt), larval rearing is still a major obstacle (Yong-Sulem and Brummett 2006a, 2006b; Yong-Sulem et al. 2006a, 2006b; Yong-Sulem et al. 2007). Being small, the larvae are vulnerable to a wide range of predators. Survival to fingerling stage averages less than 30% in most cases (Figure 1).

A fundamental problem with *Clarias* is their tendency towards cannibalism. Hundreds of person-hours invested in continual sorting of juveniles are required to avoid high levels of cannibalism. Stocking must be carefully controlled to avoid mixing fishes with too great a size variation.

As a component of the widely promoted low external input/small-scale artisanal farming systems approach to aquaculture, catfish have been included as a predator in tilapia-based polyculture systems aimed at increasing the market value of the tilapias by

Table 2: Enterprise budget (XAF) for mixed-sex Nile tilapia SME production system stocked at 3 fish/m² and grown from 5 to 150 g in 120 days (US$1 = XAF500)

	Number per cycle	Unit price	Total cost		Amount (XAF)	Percentage of total
Investment capital				**Amortization (years)**		(10.33)
Pond construction (m²)	2,000	1,000	2,000,000	10	66,667	9.39
Equipment			100,000	5	6,667	0.94
Stocking						(21.12)
Fingerlings (number)	6,000	25	150,000		150,000	21.12
Operations						(68.55)
Feed (kg)	1,027.5	250	256,875		256,875	36.17
Labor (person 8-hour days)	100	1,500	150,000		150,000	21.12
Transport (return trips to market)	4	20,000	80,000		80,000	11.26
Total production costs (per cycle)					**710,208**	100.00
Revenues					**1,027,500**	Gross
Fish sales (kg)	685	1,500				
Productivity (kg/ha)	3,425				317,292	
			Total investment	**Financing (% per month)**		
			2,736,875	0	0	Interest
					317,292	Net per cycle
Cycles per year	3				**951,875**	**Net per year**
Total fish production per year (t)	**2.05**				**34.78**	**ROI**

reducing their reproduction and increasing average size at harvest. In fishfarming theory, polyculture, the simultaneous production in the same culture unit of multiple species with complementary feeding niches, has been widely promoted as a means of improving the efficiency of feed use, a major cost element in fishfarming. However, as a component of a production system, polyculture clearly falls into the category of "hassle-prone" technology. Getting the number and quality of fingerlings of one species exactly at the time and in the condition required is one of the major problems confronting African fishfarmers at all scales. Because most fishfarms only have limited transport vehicles, holding facilities and trained staff, getting two species is more than twice as difficult as getting one. In Cameroon, the basic fish production model being promulgated by the extension service includes three species. Little wonder then, that at any given time, an estimated 40–50% of fishponds are either not stocked, understocked or incorrectly stocked.

The most successful catfish production systems that we know of are in Nigeria, mostly in the periurban zones of Lagos and Ibadan where they have easy access to large markets. Because of high rents on land and water, systems have become intensive using recirculation and aeration to produce high densities of fish in tanks (Figure 2, courtesy of John Moehl, FAO). While we do not have reliable production cost and revenue data on these farms, we can estimate how catfish monoculture might compare to tilapia monoculture and tilapia-catfish polyculture using basic principles of aquaculture business planning based on prices and on-farm growout trials conducted in Cameroon (Tables 2–5). This will give us some idea as to how and why the Nigerian system has evolved in the way it has.

For purposes of initial comparison, the productive water surface area is fixed at 2,000 m^2. Water is considered as free, although initial filling and make-up water (for evaporation and other losses) are not free in Nigeria and will not be free in most of Africa in the near future. Feed cost includes labor used in pelleting a dried, ground and blended premix purchased from local feedmills.

Table 3 shows the results for a catfish-tilapia polyculture of the type promoted by the Cameroonian National Agricultural Research System (NARS). Tilapia are stocked at 2 fish/m^2 while catfish are stocked at 1 fish/m^2 to control tilapia reproduction. Results indicate that a fishfarm of 2,000 m^2 pond surface area cannot turn a profit. As the carrying capacity of tilapia is to a large extent regulated by the ability of the pond to produce enough oxygen to keep the fish alive and growing, the overall pond productivity is constrained by the pond surface area. Table 4 shows how an increase in pond surface area from 2,000 to 3,000 m^2 makes the farm profitable.

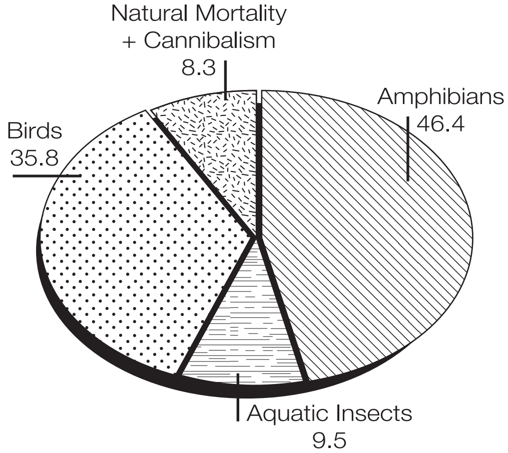

Figure 1: Sources of mortality for catfish fingerlings (Sulem and Brummett 2006b)

Figure 2: Intensive catfish production in tanks, Nigeria

Table 3: Tilapia-catfish polyculture system (2,000 m²) producing 200 g tilapia and 400 g catfish in 120 days

	Quantity per cycle	Unit price	Total cost		Amount (XAF)	Percentage of total
Investment capital				**Amortization (years)**		(6)
Pond construction (m²)	2,000	1,000	2,000,000	10	66,667	5
Equipment			100,000	5	6,667	1
Stocking				**Fish/m²**		(27)
Tilapia	4,000	25	100,000	2.00	100,000	8
Catfish	2,000	125	250,000	1.00	250,000	19
	(6,000)			(3.00)		
Operations				**Feed (kg/year)**		(68)
Feed (kg)	2,300	250	575,000	1,360	575,000	44
Labor (person-days)	80	3,000	240,000	960	240,000	18
Transport (round trip)	4	20,000	80,000	0	80,000	6
Total production costs (per cycle)				2,320	1,318,333	100
Revenues*				**Productivity (kg/ha)**		
Tilapia (kg)	402	1,500		3,371	602,328	
Catfish (kg)	283	2,500		2,379	708,621	
Productivity (kg/ha)				5,750	1,310,948	Gross
Capacity anticipated	3,425				-7,385	
*assuming 85% survival rate tilapia; 60% catfish	Natural = 300		**Total investment**	**Financing (% per month)**		
	Compost = 2,450		3,345,000	0	0	Interest
	Feed = 3,425				-7,385	Net per cycle
Cycles per year	3				**-22,155**	**Net per year**
Production total (t)	2.06				**-1**	**ROI**

Table 4: Tilapia-catfish polyculture system (3 000 m²) producing 200 g tilapia and 400 g catfish in 120 days

	Quantity per cycle	Unit price	Total cost	Amortization (years)	Amount (XAF)	Percentage of total
Investment capital						(7)
Pond construction (m²)	3,000	1,000	3,000,000	10	100,000	7
Equipment			100,000	5	6,667	0
Stocking				**Fish/m²**		(34)
Tilapia	6,000	25	150,000	2.00	150,000	10
Catfish	3,000	125	375,000	1.00	375,000	25
	9,000			3.00		
Operations				**Feed (kg/year)**		(59)
Feed (kg)	2,300	250	575,000	2,040	575,000	38
Labor (person-days)	80	3,000	240,000	1,440	240,000	16
Transport (round trip)	4	20,000	80,000	0	80,000	5
Total production costs (per cycle)				3,480	1,526,667	100
Revenues*				**Productivity (kg/ha)**		
Tilapia (kg)	602	1,500		2,247	903,491	
Catfish (kg)	425	2,500		1,586	1,062,931	
					0	
Productivity (kg/ha)				3,833	1,966,422	Gross
Capacity anticipated	3,425				439,756	
*assuming 85% survival rate tilapia; 60% catfish	Natural = 300		**Total investment**	**Financing (% per month)**		
	Compost = 2,450		4,520,000	0	0	Interest
	Feed = 3,425				439,756	Net per cycle
Cycle/year	3				**1,319,267**	**Net per year**
Production total (t)	3.08				**29**	**ROI**

Table 5 illustrates the case for a catfish monoculture. Catfish, by being able to breathe atmospheric oxygen can be stocked at a higher rate; the final size at harvest being mostly dependent upon stocking and feeding rates, that is the “intensity” of the system. Even though catfish fingerlings are five times as expensive as tilapia and the food conversion efficiency in catfish monoculture is lower (2.0 vs. 1.5 in polyculture system), the higher market value of catfish more than compensates.

CONCLUSION

Despite the hassles associated with catfish fingerling production, a comparison of tilapia monoculture, tilapia-catfish polyculture and catfish monoculture budgets clearly shows the incentives that are driving fishfarms toward more catfish-based systems. This is not only dependent upon the (currently) important market price differences between tilapia and catfish, but also the physiological ability of catfish to withstand intensification.

In addition to the analysis above, the increasingly high costs of land and water in Africa and elsewhere mean that increasing production by increasing surface area under culture will become ever more expensive and impractical. In situations where roads and communications are poor, close proximity to markets is essential, and land/water prices are generally higher the closer one gets to the city and the greater the incentive to intensify.

Considering just the differences in profitability, fish production and reduced hassles involved in monoculture vs. polyculture, farmers in many places can be expected to continue the shift from tilapia to catfish and from low-intensity to high-intensity systems. Taking into account the taxable revenues generated, the number of jobs created and the amount of fish locally marketed by the higher intensity systems, governments and development agencies should likewise review their emphasis on low external input/artisanal aquaculture in favor of SME investments. Areas where NARS could productively invest include improved technology for catfish larval rearing and selective breeding to produce catfish lines that perform well in high-intensity culture.

Table 5: Enterprise budget for *Clarias* production in earthen ponds and raised from 5 to 400 g in 120 days

	Quantity per cycle	**Unit price**	**Total cost**		**Amount**	**Percentage of total**
Investment capital				**Amortization (years)**		(4.21)
Pond construction (m²)	2,000	1,000	2,000,000	10	66,667	3.82
Equipment			100,000	5	6,667	0.38
Stocking				**Fish/m²**		(43.02)
Fingerlings (number)	6,000	125	750,000	3	750,000	43.02
Operations						(52.77)
Feed (kg)	2,880	250	720,000		720,000	41.30
Labor (person 8-hour days)	80	1,500	120,000		120,000	6.88
Transport (round trip)	4	20,000	80,000		80,000	4.59
Total production costs (per cycle)					1,743,333	100.00
Revenues					3,240,000	
Fish sales (kg)	1,440	2,250				
Average weight (kg)	0.400				1,496,667	Gross
			Total investment	**Financing (% per month)**		
Survival rate	0.6		3,770,000	0	0	Interest
					1,496,667	Net per cycle
Cycles per year	3				**4,490,000**	**Net per year**
Total fishproduction per annum (t)	4.32				**119.10**	**ROI**

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GENETIC IMPROVEMENT AND EFFECTIVE DISSEMINATION: KEYS TO PROSPEROUS AND SUSTAINABLE AQUACULTURE INDUSTRIES

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SUMMARY

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

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

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

BACKGROUND AGAINST WHICH GENETIC IMPROVEMENT PROGRAMS OPERATE

An ever-increasing human population, better economic situation in some sectors, and greater awareness about the health issues in relation to food, have resulted in a greater demand for fish in the world. Since capture fisheries have stagnated, fish farming has become a very fast growing food production system.

FISH GENETIC IMPROVEMENT CAN HELP ACHIEVE SUSTAINABLE GAINS

Genetic improvement programs have the following highly desirable attributes:

1. Power to modify the animal to suit a purpose or environment.
2. Greater food security and poverty alleviation by increasing productivity, reliability and consistency – and the gain may be permanent.
3. Solutions to existing or emerging pathogens and to environmental challenges.
4. Favorable return on investment.
5. Help in filling the gap between demand and supply without a negative environmental impact.
6. Assistance in managing inbreeding in the production system.

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

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

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

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

STEPS IN THE DESIGN OF A GENETIC IMPROVEMENT PROGRAM

GENERAL

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

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

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

BRIEF TREATMENT OF EACH STEP

1. DESCRIPTION OF THE PRODUCTION SYSTEM(S)

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

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

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

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

2. CHOICE OF THE SPECIES, STRAIN(S) AND BREEDING SYSTEM

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

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

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

3. FORMULATION OF THE BREEDING OBJECTIVE

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

There are two main ways of defining the breeding objective:

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

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

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

4. DEVELOPMENT OF SELECTION CRITERIA

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

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

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

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

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

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

5. DESIGN OF GENETIC EVALUATION SYSTEM

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

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

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

6. SELECTION OF ANIMALS AND OF MATING SYSTEM

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

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

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

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

7. DESIGN OF SYSTEM FOR EXPANSION

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.

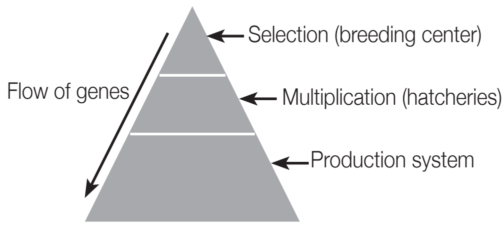

Figure 1: Flow of genes from the breeding center to the production system

Fish 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 program in a relatively small number of animals can be enough to service a very large population involved in production.

Unfortunately, experience shows that when a successful strain 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 perhaps through the creation of a formal structure that is not only technically sound but also regulates the process and enables the implementation of quality assurance practices. Box 1 illustrates in a diagrammatic form important considerations that should be made when planning and putting in place a logically based system for the dissemination of improved stock of aquatic species.

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

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

8. MONITORING AND COMPARISON OF ALTERNATIVE PROGRAMS

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

Box 1: Considerations to be made during the planning and putting in place of a formal scheme for the dissemination of improved stock from breeding centers to fish farmers

There are options, but we have to consider…

- The resources available
  - Staff
  - Facilities
  - Capital
  - Operating locations
- Competence or access to it
- Size and other characteristics of the industry to be serviced
- Industry level in terms of technology application and education of members

Options for multiplication

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

Creation of a network of hatcheries

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

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

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

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

WHAT SORT OF RESPONSE CAN SELECTIVE BREEDING ACHIEVE?

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

CONCLUDING REMARKS

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

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

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

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

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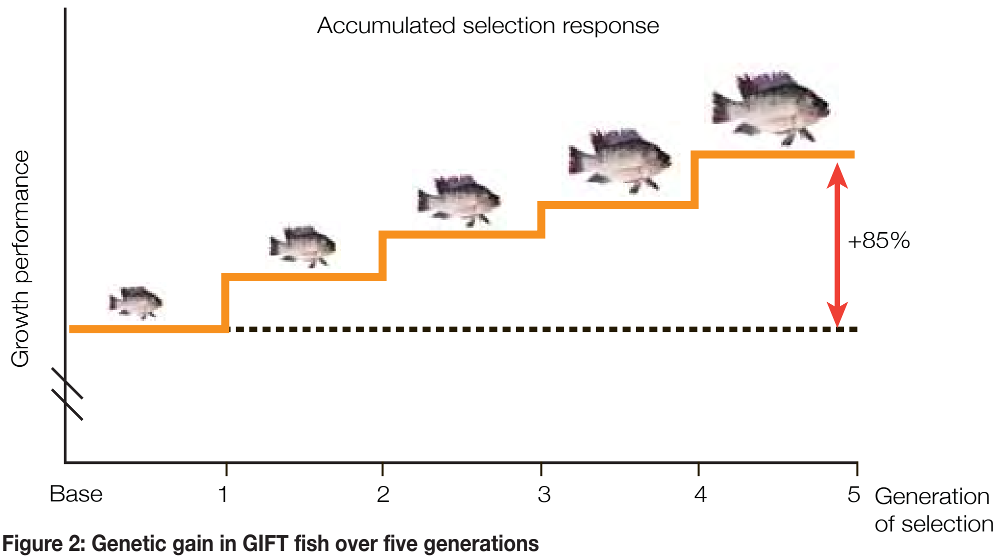

Figure 2: Genetic gain in GIFT fish over five generations

GENETIC IMPROVEMENT OF *CLARIAS GARIEPINUS* AT THE WORLDFISH CENTER, ABBASSA, EGYPT

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INTRODUCTION

Fish production is viewed as an important tool to close the gap between supply and demand for animal protein in Egypt. Production from natural fisheries is estimated to be at a maximum sustainable level. Over a 10-year period, 1996–2005, total capture increased from 340,434 to 349,553 tonnes Fish farming is the only available means to achieve a significant improvement in fish production. The aquaculture system in Egypt is largely dependent on Nile tilapia, *Oreochromis niloticus*, with smaller contributions from mullets, carps and Clariid catfishes to total production.

Production of African catfish, *Clarias gariepinus*, so far, is mainly from capture fisheries. Use of the species for farming has encountered a number of obstacles including problems with reproduction and fry maintenance, and poor reputation among customers based mainly on its natural feeding habit as a scavenger. Establishment of catfish as another major aquaculture species should help in diversifying aquaculture production and avoiding the drawbacks of a system that is largely based on a single species. African catfish is endemic to all freshwater bodies in Egypt. The potential for its use in Egyptian aquaculture is very high because of several factors related to the aquaculture system, the species itself and existing market forces.

African catfish has several biological traits that make it a suitable species for aquaculture. Fish reach sexual maturity within the second year of their life, feed low on the food web, reach market size within the first season of growth and tolerate harsh environmental conditions. They are also suitable for polyculture, highly acceptable on the market and can survive for several hours even outside the water which minimizes their transportation requirements to the market.

Little has been done to improve aquaculture performance of African catfish. Therefore, the potential for genetic improvement of the species is very high. Research and applications using hybridization (Legendre et al. 1992; Nwadukwe 1995; Senanan et al. 2004); gynogenesis and androgenesis (na-Nakorn et al. 1993; Bongers et al. 1995); cytogenetics (Teugels et al. 1992; Nagpure et al. 2000a, 2000b); and biochemical and molecular markers (Agnese and Teugels 2001; Sukmanomon et al. 2003; Poompuang and na-Nakorn 2004; Senanan et al. 2004; Islam et al. 2007) were accomplished. The WorldFish Center is carrying out the world's first genetic improvement project of *Clarias gariepinus* that uses selective breeding technology. In this paper, the various aspects of this project will be discussed.

EXPLORATORY INVESTIGATIONS

The beginning of the project was a thorough assessment of the current state of knowledge concerning the biology and potential for economic production of African catfish. While limited knowledge of the basic biology and fishfarming requirements of the species exist, further information was needed to support the initiation of a selective breeding program. Most of the available information is concerned with mass spawning and reproduction, bulk rearing of resulting fry, and fishfarm use of *Clarias*, mostly as a means to control reproduction and suppress unwanted fish population in the fishfarm. Proper and elaborate selective breeding programs require complete separation of spawns, identification of full-sib groups and their relationship with other individuals in the population, spawning dates of each fish and impact of rearing environments at different stages of life on performance of individual fish and families. This justifies the need for a reliable method for the identification of individual fish throughout the experimental period and keeping accurate records on ancestry and performance of all individuals from one generation to the next.

Production of families in isolation and their tagging necessitated conducting several experiments to identify new techniques and to solve specific problems with others concerning:

1. Achievement of pairwise reproduction
   a. success of pairwise spawning in hapas
   b. choice of suitable hapa material
   c. success of paternal second spawning
2. Separate rearing of families until tagging
   a. rearing environments
   b. water quality
   c. cannibalism among fry
   d. stocking density
   e. feeding
3. Tagging
   a. suitable age and size for tagging
   b. type of tag
   c. tagging technique
   d. use of anesthesia
   e. tag loss at stocking
   f. tag loss until harvest

The purposes of this exploratory study were to:

1. gain a better understanding and control on the reproduction of African catfish, *Clarias gariepinus*, stocks obtained from different geographical locations and crosses between them;
2. be able to reliably rear and tag the resulting fry;
3. close the life cycle under conditions required for practical selective breeding; and
4. identify potential problems associated with the above-mentioned activities and possible solutions.

COLLECTION OF BROODFISH

Communications with potential providers of broodfish were established in spring of 2004. Arrangements were made to transfer broodfish in August 2004 from the original locations to the research station at Abbassa. *Clarias* broodfish were collected from Abbassa, Kafr El Sheikh and Fayoum. The Fayoum stock was originally collected from Rasheed on the Mediterranean coast (Figure 1). Subsequently another stock was obtained from Al Kanaes, Beheira, in the summer of 2005. The numbers of individuals obtained from each of the locations are shown in Table 1. Provision of mature *Clarias* as a source of pituitary glands for use in stimulation of spawning was arranged from the production ponds at the Abbassa experimental station.

SPAWNING AND FRY PRODUCTION

After collection of *Clarias gariepinus* stocks, each of them was maintained separately in a 200 m^2 concrete-walled pond. Mating arrangements were made in another earthen pond that had nylon netting hapas, 125×80×100 cm (length×width×depth) installed inside external cotton cloth hapas that were used to prevent escape and mix-up of fry from different families and to assess the possibility of the very fine hatchlings

Table 1: Number of male and female *Clarias gariepinus* obtained from different locations within Egypt for use in the study of reproductive biology and the subsequent initiation of a genetic improvement program for increased body weight

Stock	Female	Male
Abbassa	85	35
Kafr El Sheikh	44	25
Beheira*	58	32
Rasheed	52	33
Total	239	125

* This was the last stock that was obtained in summer of 2005. It was not included in the initial trials conducted in 2004 although it was included in the selection program in 2005.

passing through the mesh of the internal nylon netting hapas once they hatch and swim up (Figure 2).

Females were checked for readiness to spawn. Ready-to-spawn (mature) females were identified based on their secondary sexual characteristics and the release of ripe eggs on gentle pressure applied to the lower part of the abdomen (Figure 3). Those expected to be mature or close to maturity were selected, weighed and assigned to the breeding hapas.

A male of matching weight was paired with each female in a separate hapa on 15 August 2004. The top of the hapa was closed by stitching to prevent fish from jumping out. Water temperature throughout the spawning period varied between 26ºC and 30ºC. Fluctuation of temperature was limited by the size of the pond (2,000 m^2) where the trial was conducted. Hapas were inspected for spawning on 16 August. Pairs that did not spawn were allowed another 24 hours and inspected again. Pairing combinations and number of spawns obtained in each combination are shown in Table 2. Only one

Figure 1: Map of northern Egypt showing the locations (✭) where African catfish, *Clarias gariepinus*, broodfish were collected

additional incidence of spawning occurred on 17 August. Further extension of the spawning period was associated with a drastic increase in number and severity of injuries, fin erosions and even mortality of broodfish, but not spawning.

Figure 2: Spawning hapas (green) with outer cloth hapas (white); the top of the spawning hapas was stitched to prevent escape of broodfish

Figure 3: The lower abdomen and the genital area of a gravid female catfish are shown; release of ripe eggs signals the female's readiness for spawning

Spawning usually took place during the night. Sticky eggs were found scattered all over the bottom and the walls of the inner hapa in the next morning. Broodfish were removed and a sample of eggs was collected (Figure 4) and checked for occurrence of fertilization. Broodfish were removed from the hapas and males were saved for use in a second spawn that was attempted 1 and 2 weeks after the first spawn. Hatching was observed on the following day. Females obtained from Kafr El Sheikh were the latest to be introduced to the research station and were expected to exhibit poor maturation and spawning success. A total of 31 females spawned, 30 of which produced fry out of 40 females that were identified as ready to spawn and 20 that were identified as less ready. Of the 31 spawns, 29 were obtained from the ready-to-spawn group while 2 came from the less-ready females. This observation signifies the importance of accurate broodstock selection by experienced personnel for natural spawning.

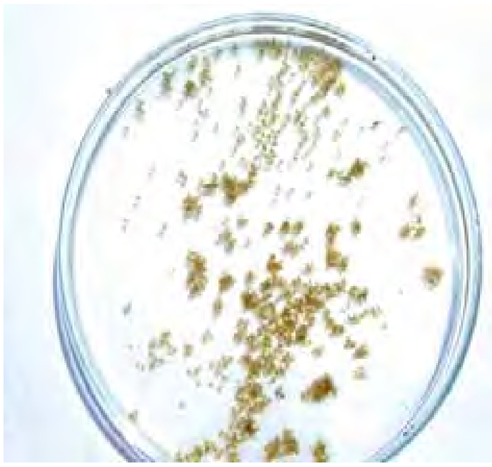

Figure 4: Fertilized catfish eggs collected from the bottom of the spawning hapa

Table 2: Number of spawns/number of pairs used in the initial trials of reproduction in different mating combinations between stocks of *Clarias gariepinus* collected from different geographical locations within Egypt

Males	Females Abbassa	Kafr El Sheikh	Rasheed	Male spawning occurrence/line
Abbassa	4/4	3/5	4/5	11/14
Kafr El Sheikh	3/4	2/4	5/7	10/15
Rasheed	3/3	2/4	4/4	9/11
Total spawning/line	10/11	7/13	13/16	30/40

Males that reproduced successfully in mid-August were used in a trial toward producing a second spawn with new unspawned females. Spawning success was evaluated 1 and 2 weeks after the first spawn. Success level was very limited. Only 4 spawns were produced from the 30 pairs that were allowed to mate. Out of the 4 spawns, there was 1 spawn that produced fry. The other 3 spawns did not produce any fry. Another attempt was conducted 1 week later with the use of catfish pituitary extract (CFPE) injections to enhance spawning. No spawns were obtained but a drop in water temperature (22–26°C) during that period may have contributed to the lack of reproductive activity.

Several attempts were conducted to accomplish a second spawn in hapas installed in heated and covered concrete tanks. Different levels of CFPE were used to enhance spawning in both males and females. Again, no spawning was observed.

The trial indicated the following:

1. Reproduction can be accomplished while maintaining the integrity of full-sib families.
2. Crossing between strains can be accomplished successfully. Reproductive isolating mechanisms do not appear to be a problem according to the trial that was conducted.
3. Production of a second spawn was not successful, possibly because of unfavorable temperature. This was attempted again in 2005 and produced positive results.

FRY REARING

In spite of the fine-mesh size of the spawning hapas, a small number of sac fry passed through the mesh in several of the inner hapas indicating that fry size upon hatching is marginal to the mesh size of the material that was used. At the same time, it was felt that using smaller mesh size might cause problems because of its effect on fouling and the anticipated problems with water exchange which might in turn have an effect on fry health and survival. Individuals that were found in the outer, cloth hapa were collected on the third day and placed back with their full-sibs inside their respective inner hapas at which time they were large enough to remain inside the mesh hapas. No fry were observed in the outer hapa later. The outer hapa was then removed and fry were kept in the mesh hapa until the end of the first week after hatching (Figure 5). The resulting fry were then counted and fry numbers per family were standardized at 300 fry per family.

Fry were then reared in the hapas for 2 weeks. Rapid growth was noted up to an average of 0.5–1.0 g but then slowed down. A drastic decrease in the number of fry per family was noted during sampling. A notable divergence of the size of fry was also observed (Figure 6). The loss of fry was suspected to affect growth rates in different families. The reason for the loss was unclear at this stage but cannibalism within the full-sib families was suspected as a possible reason. Accordingly, two trials

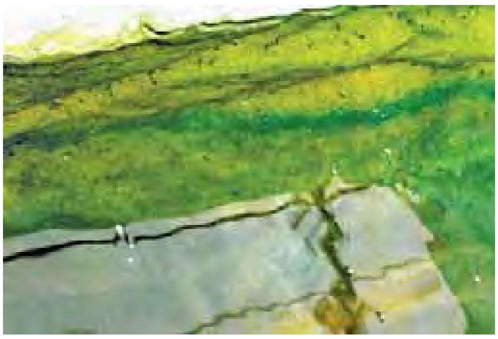

Figure 5: Swim up fry, 4 days old, in the spawning hapas

Figure 6: Size variation within a single full-sib group of Clarias gariepinus

were set up to explore certain aspects of rearing techniques that may help in growing a reasonable number of fry to a size/weight that is suitable for PIT (Passive Integrated Transponder) and Floy tagging. One trial was conducted to investigate growth rates in hapas at different stocking densities. The other was conducted to explore the impact of cannibalism on fry loss.

FRY GROWTH

Because of the divergence in fry sizes within each full-sib group, fry were sorted by size into two groups, large and small. Large fry, jumpers, were saved while small fry, which represented the majority of the fry in each hapa, were used in this experiment. Fry from different hapas were not mixed because we were mainly interested in identifying conditions that would lead to all, or most, of the families reaching tagging size within a suitable timeframe (e.g., 2 months). A set of two hapas, 1 m^3 and 6 m^3, was installed for each of the fry hapas. Two subgroups of 50 and 60 fry were drawn at random from each of the fry hapas and stocked in the 1 m^3 and 6 m^3 hapas, respectively, to make a stocking density of 50 and 10 fry m^{-3}, respectively. Fish were fed to satiation at three-day intervals.

Fish in the hapas were sampled 2 weeks after stocking and then monthly. Upon collection of the sample, fry were counted and weighed in bulk to estimate growth rate. Mean weight in the two treatments was assessed to identify a suitable stocking density for the practical rearing of fry towards a suitable size and timeframe for tagging. Based on results obtained from this trial, on one hand, a stocking density of 50 fry m^{-2} was not suitable for production of *Clarias gariepinus* fry at a suitable size for tagging. A stocking density of 10 fish m^{-2}, on the other hand, resulted in suitable tagging size fry within a period of 6 weeks (Figure 7).

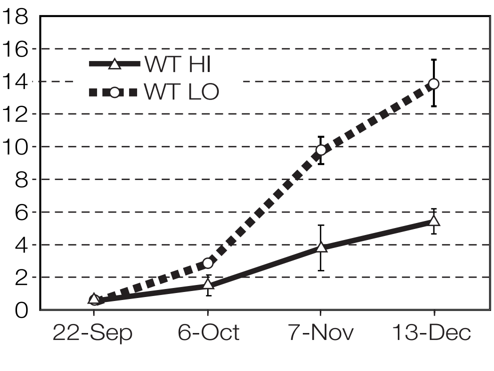

Figure 7: Mean weight of *Clarias gariepinus* fry stocked at high density (50 fry m^{-2}), and low density (10 fry m^{-2}) in fine-mesh hapas; vertical bars represent standard error of the mean at the given date and stocking density

CANNIBALISM WITHIN FULL-SIB GROUPS

A set of 4.5 m^3 hapas, 3.0×1.5×1.0 m (length×width×height), was installed in the same manner as described above to evaluate the possibility of jumpers preying on their smaller siblings. Hapas were each stocked with 25 jumpers (predator group) and 150 small fry (prey group). Feeding and other daily maintenance treatments were applied in the same manner as described in the fry growth experiment except that a total count of fry in each hapa was conducted at the end of 1 week after stocking. Comparative fry count of the two groups was used to explain the cause of fry mortality within full-sib groups. No fry loss was observed in the predator group (0%). Comparatively, an average fry loss of 47% was observed in the prey group. This observation suggests that cannibalism was the main reason for fry loss in all the families. Natural mortality both in the predator group and in the fry growth trial suggests ruling out this factor as an important cause for mortality in this stage of life.

INVESTIGATION OF TAGGING TECHNIQUES

As some families contained larger fry, exploratory tagging of large fry was conducted later in the year on 15 September. Floy tags were used in this trial. Using 420 candidates with a mean weight (SE) of 12.1 g (3.2), survival after tagging was 92%. It appeared from this exploratory trial that the size of fish is highly important for the success of tagging with the critical point being around 5 g. Fish that were less than 5 g did not have a well-developed dorsal muscle that can hold the tag.

Based on this, the fry rearing experiment was continued for all fish groups to exceed or reach this mean weight. In December 2004, fish from the fry rearing experiment averaged 5.4 g and 13.9 g for the 50 fry m^{-2} and 10 fry m^{-2}, respectively. Random samples from all families in the 50 fish m^{-2} group were allocated to Floy and PIT tagging to evaluate survival after tagging.

Different tag types resulted in different rates of tagging success. Survival within 2 weeks after tagging was 21% and 84% in the Floy-tagged and the PIT-tagged groups, respectively. Most of the mortality took place within 2 days after tagging, suggesting that Floy tagging may cause more stress on the tagged fish. Subsequent mortality was associated with development of ulcers and diseases. Based on this, it was clear that PIT tagging was the technique of choice for *Clarias gariepinus* fingerlings. A second stage of the experiment was conducted to confirm the hypothesis that difficulties with Floy tagging are due to the body form of the fish and the lack of a thick dorsal muscle and body depth that would have facilitated tag insertion on one side and to focus in on the most suitable size of fish for PIT tagging.

A sample of fish from the 10 fish m^{-2} group with an average weight of 14.1 g was used for Floy tagging. A total of 160 fish were tagged. Mortality subsided 2 days after tagging. Survival, 3 days after tagging, was 75%. For PIT tagging, the two groups of fish, 50 fish m^{-2} and 10 fish m^{-2}, were graded. Some 100 individuals with an average weight of 7.8 g were obtained through grading of the 50 fish m^{-2} group while 100 individuals with an average weight of 10.3 g were obtained by grading of the 10 fish m^{-2} group. Survival after PIT tagging of the two groups was 97% and 94%, respectively. While 5 g appears to be a reasonable minimum size for PIT tagging, it may be safer to grow fry to a larger size than 5 g prior to PIT tagging.

COMMUNAL STOCKING

Fish were stocked communally in a pond at 4 fish m^{-2} during the first week of March 2005. Samples were collected biweekly to evaluate growth and Floy tag retention. Tag retention rate continued to drop gradually until fish reached a mean weight of 80 g in mid-May. At that time, tag retention rate was 77%. Subsequently, tag retention started to drop much faster. It was, in the PIT-tagged fish, much better. Until mid-May, only 1 fish lost the tag from a total of 247 fish. Fish survival in September 2005, after a 6-month growth period, was 68% including fish that lost tags. Mean weight was 234 g. There may be a need to use a lower stocking density or change the rearing conditions to obtain market-size fish in the experimental ponds.

SELECTION PROGRAM IN 2005

The breeding program conducted by the WorldFish Center in Egypt to improve growth performance of *Clarias gariepinus* is the first in the world. Preparations for the reproduction season started in the summer of 2005. All four stocks were separated in ponds by sex and fed with 32% protein diet. Females were regularly sampled and checked for readiness to spawn. When ready to spawn, males and females were paired in hapas that were installed in a 4,000 m^2 earthen pond. Very limited spawning success was achieved where only 9 spawns were obtained from a total of 150 pairs. It was then decided to move the fry production phase into covered concrete tanks where the set of hapas may be protected from the unstable weather conditions and more control can be practised on the fluctuating water temperature. Further, intraperitoneal injection of Ovaprim, 0.5 mg/kg of female weight, was used. The results were very encouraging where 32 pairs that were injected produced 25 spawns, of which 21 produced fry. CFPE injections were also attempted and produced comparable results. The spawning activity continued through most of September to produce a total of 82 full-sib and half-sib groups. These were the progenies of 52 sires and 82 dams.

Fish numbers per family were standardized to 50 per family and stocked in 4.5 m^3 hapas installed in an earthen pond. The remaining fish from each family were kept in a separate hapa as a backup. Because production of families was accomplished much later in the season than in the 2004 spawning season, the fish did not reach tagging size in 2005 because of the lower temperature after spawning and the start of winter during which time fish exhibited minimal increase in weight as revealed by periodic sampling.

In February 2006, a parasitic infestation, *Ichthyophthirius multifilis*, was successfully treated but left only a total of 1,075 survivors. Tagging was conducted in May and fish were communally evaluated. Of the animals stocked, 73% were recovered with tags. Mortality during communal evaluation was 15%. Tag loss among the survivors was 14%. Data were collected on sex, individual body weight, standard length, head length, head width, head depth, body width and caudal width (Table 3). It was important at this stage to evaluate several traits in order to identify a suitable selection criterion that best expresses the genetic components of variation in growth. Preliminary results (unpublished) indicated that there was genetic variation in body and morphometric traits.

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Table 3: Basic statistics for body traits in African catfish

Traits	Mean	Standard deviation	Coefficient of variation (%)
Harvest weight	676.54	189.87	28.1
Standard length	468.35	41.25	10.3
Head length	106.19	11.09	10.4
Head width	69.99	7.42	11.0
Head depth	39.85	4.23	10.9
Body width	55.13	6.83	12.4
Caudal width	38.49	4.64	12.2

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PROSPECTS FOR DEVELOPMENT OF A GENETIC IMPROVEMENT PROGRAM IN AFRICAN CATFISH (*CLARIAS GARIEPINUS*)

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INTRODUCTION

In this paper we discuss the prospects for the development of a genetic improvement program for African catfish (*Clarias gariepinus*). We do not aim to make an exhaustive review of the literature. Based on available knowledge and some preliminary research results obtained by WorldFish, pre-requisites for the initiation of genetic improvement in this species can be satisfactorily met, although control of reproduction in males may require further refinements. We modeled alternative breeding schemes, with an emphasis on development of breeding objectives, selection strategies, and choice of testing environments. In parallel with the development of improved pure strains of African catfish, we also considered possibilities to exploit heterosis and complementary effects in this species. We also present some thoughts on technical issues of other genetic techniques such as sex reversal and chromosome manipulation. Given the advent of molecular genetics and reproductive technologies, we outline potential applications of marker assisted selection, and in-vitro fertilization using fresh or frozen sperm in practical selective breeding programs. Finally, strategies for effective dissemination of improved fish to farmers are also discussed.

CHOICE OF THE SPECIES

Clarias gariepinus is one of the African species of choice for future genetic improvement. It is widely distributed and cultured in many African countries, especially in Nigeria where it is the most important species, and in Cameroon, Ghana, and South Africa where it ranks high among the cultured species. Although official statistical figures about total culture area and yield are not always available, production of *C. gariepinus* has been recognized as a growing one, positively contributing to the social and economic development of many countries in the region. Relative to other African catfish or species, *C. gariepinus* shows several advantages under a wide range of culture conditions, including fast growth on an omnivorous diet and resistance to low dissolved oxygen and stress. Its biology and ecology are detailed by Brummett in this volume.

In spite of its high production potential, scientific knowledge in the area of genetics for this species is still very limited, and there is a paucity of information about discrete populations of *C. gariepinus* within each country or in Africa as a whole. Some earlier studies indicate differences in levels of heterozygosity between the wild and domesticated farm fish (Teugels et al. 1992; Grobler et al. 1994; Van der Bank 1998). Growth of farmed fish has declined due to poor management practices of hatcheries which have not been based on sound genetic norms for brood stock maintenance and replacement, and for progeny production.

As a first step in the proposed genetic improvement program, a founder population based on the best stocks from different geographical areas within sub-regions of Africa should be established. Priority should be assigned to genetically distinct populations, which may be identified by characterization at the molecular level prior to sampling if resources permit. Note that there is a weak correlation between molecular information and phenotypic performance in many species (see review by Reed and Frankham 2001). The level of heterozygosity derived from marker analysis does not ascertain genetic potential of the population for performance. Before assembling the foundation populations, a well designed experiment should be carried out to evaluate performance of locally (regionally) available stocks. Identification of superior stocks to be included in the breeding programs can result in gains equivalent to a few generations of selection, thus saving time and resources. Depending on availability of experimental facilities and resources, four or five stocks included in a complete diallel cross can be sufficient to capture abundant genetic variation in the synthetic population for future selection (Holtsmark et al. 2006). The strategy has proved successful in farmed aquaculture species such as Atlantic salmon (Gjedrem et al. 1991), Nile tilapia (Eknath et al. 2007) and Indian rohu carp (Mahapatra et al. 2006).

PRE-REQUISITES TO START BREEDING PROGRAMS FOR A NEW SPECIES

A formal breeding program in any species requires i) individual tagging, and ii) control of reproduction. Exploratory experiments carried out at the WorldFish Center in Abbassa, Egypt (Rezk 2008 in this volume) indicate a high success rate with individual identification in African catfish using PIT tags (passive integrated transponder). A suitable size to be physically tagged is around 5 g or above. Mortality after tagging is low (less than 5%). Throughout the rearing period of one month in hapas, the retention rate is approximately 96%. In practice, further improvement in survival and tag retention may be achieved in a number of ways. A common practice is that fingerlings should be collected from nursery ponds one day before tagging. They should be kept in tanks without any feed overnight so that more space will be available in the abdominal cavity for accommodating the PIT tags (this does not apply to cases in which the tags are injected into the dorsal muscle). One or two days after tagging, all the fingerlings should be pooled in conditioning tanks without feed before releasing them to communal grow-out in test environments. Tagging of additional fish should be done to replace dead fish from each family. The success of early tagging in African catfish is important because it can shorten the period of separate family rearing in tanks or hapas. In aquaculture species larvae and fry are too small to be physically tagged immediately after birth. Individual families are thus kept in separate hapas which induce an effect common to full-sibs sharing the same environment (c^2). In freshwater fish species (e.g. tilapia), the c^2 estimated ranges from 10 to 30% (Ponzoni et al. 2005; Nguyen et al. 2007).

Further, a fully pedigreed breeding program requires pair matings to enable unequivocal identification of parentage (not mass spawning). A mating ratio of one male to one or two females is often applied, depending on family structure and experimental design. Induced breeding using human chorionic gonadotropin (HCG) or catfish pituitaries is not a problem in females, but stripping sperm from males still remains impossible due to the physiology of the testis. This may make the implementation of more elaborate mating schemes difficult or impossible (e.g., incomplete factorial design or factorial mating by set). An experiment at Abbassa was conducted to examine alternative reproduction systems for this species (Rezk, 2008 in this volume). By lowering the water level in the pond in order to increase water temperature (optimum around 25ºC), natural spawning of parental pairs was achieved in hapas. The success rate of mating was greater than 80%, although mating of males with a second female sometimes required the injection of a low dose of hormone for males. In this scheme, identification of ‘ready to spawn’ (or ripe) females to pair with males is critical. Ideally, females should be greater than 1.5 years of age; however, this would prolong the production cycle and increase the generation interval. Under a well controlled environment, females can reproduce effectively at 1 year of age which can shorten the generation interval in this species. Also note that the egg size increases with age of females. There are thus possibilities of maternal genetic effects on traits during early stages of growth. Genetic evaluation systems should include the maternal genetic effects if they are tested to be significant. In summary, natural spawning of African catfish in hapas is feasible, although there is still room for further improvement to ensure that the benefits from mating parents of high genetic value are fully realized.

POSSIBLE BREEDING SCHEMES

Due to the important role of *Clarias gariepinus* for aquaculture in Africa, several countries on this continent have shown great interest in developing genetic improvement programs for this species. It is, however, impossible to run individual programs in each country. Genetic improvement programs require an initial investment as well as funding for recurrent annual running costs, and a physical infrastructure and skilled human resources. A proposed strategy is to establish sub-regional breeding programs in West-Central, East and southern Africa linked to a research and training facility at Abbassa, Egypt in North Africa. The programs can develop one or more improved lines of *C. gariepinus* for use within each sub-region.

Regardless of locations or regions, the genetic improvement program for African catfish should start with selection for body weight at harvest. Food security is still an issue in African countries, and the fish are priced based on live weight (or size) at local markets. So far, information about the level of genetic variation in body traits is not available for African catfish, although phenotypic difference in growth among juvenile individuals was observed by Martin et al. (2005). Assuming that the heritability for market weight in African catfish is 0.30, and the maternal and common environmental effect is 0.15, the genetic gain may be predicted to be in the order of 10% per generation (one year), as reported for other species (e.g. Ponzoni et al. 2005). The accumulated genetic gain of the program after 3 or 5 years would be 30 and 50%, respectively.

Once the improvement of body weight is satisfied and as the program unfolds, the breeding objectives for African catfish could be expanded to include other traits of economic importance (survival and feed intake). Survival is one of the major technical constraints in hatcheries and grow-out systems for catfish. Survival rate affects the number of fish harvested and marketed. Maximizing viability of the fish is the ultimate target of any production system.

Feed is a major production cost, accounting for 60-70% of the total. Genetic improvement in growth is undesirably associated with increased feed intake. The bigger fish will eat more and thus add costs to production systems. Therefore, inclusion of the three traits (harvest weight, survival and feed intake) in the breeding objectives for *C. gariepinus* is perceived to be sufficient for the medium term future. Other important traits such as fillet yield, flesh quality and disease resistance may emerge as candidates at a later stage. We used an economic model based on a standard profit equation defined as the difference between costs and returns to derive economic values for the traits in the breeding objective. Details of the approach are given in Ponzoni et al. (2007). Unfortunately, parameters for production traits in African catfish were not found in the formal literature. We made a number of assumptions regarding growth data and parameter estimates as shown in Table 1.

Means and standard deviations for body weight are adapted from Volckaert and Hellemans (1999) and were used to develop likely heritability values. Parameters for survival rate and the genetic correlation between body weight and survival are taken from the means of 14 studies reviewed in the literature. Feed intake was calculated assuming a feed conversion ratio of two during the grow-out period. A coefficient of variation (30%) was assumed to calculate the phenotypic standard deviation for feed intake. Heritability for feed intake and its correlations with body weight and survival are not available for any aquaculture species, and hence they were adapted from the literature review of several studies in animals. In terms of population structure, the following assumptions were made:

i) the pedigree consisted of 100 families (50 sires and 100 dams),
ii) there were 20 female and 20 male progeny tested per family, that were potential selection candidates,
iii) the proportions of selected animals were 15% in females and 7.5% in males (three times greater than the actual need in both sexes), and
iv) selection was based on BLUP using full pedigree information.

Note that feed intake was included in the breeding objectives, but it was not considered as a selection criterion due to a lack of practical methods of measurement. The genetic change per year for individual traits in the breeding objective, standard deviations of the index and of the breeding goal, accuracy of selection, and overall gain in economic units are presented in Table 2.

Table 1: Phenotypic and genetic parameters for harvest weight (BW), survival rate (SR) and feed intake (FI) in African catfish

	BW (g)	SR (%)	FI (g)
Mean	1000	85	2000
h^2	0.30	0.10	0.25
σ_P	161	35.7	400
Phenotypic (above) and genetic (below) correlations			
BW		0.20	0.70
SR	0.20		0.3
FI	0.70	0.30	
Common environmental effects and correlations			
c^2	0.15	0.08	0.15
BW			
SR	0.20		
FI	0.70	0.20	

Table 2: Genetic gain per year (Δ_G) for each trait, standard deviation of (σ_I) the index and of the breeding goal, accuracy of selection ($r_{IH} = \sigma_I/\sigma_H$) and overall gain in economic units; all figures in dollars ($) refer to US dollars

Genetic gain and Index property	Actual unit
Harvest weight (g)	63.5
Survival (%)	5.2
Feed intake (g)	111.4
σ_H ($)	184.4
σ_I ($)	59.9
Accuracy of selection	0.33
Δ_G in economic units ($)	102.6

The selection environment of our choice is in earthen pond with standard commercial feed and management practices. Pond culture is the prevailing environment (>90%) in a majority of African countries, especially in Nigeria, Ghana, Kenya and Malawi, which are likely to become key players in the development of breeding programs for African catfish. There are also other production systems such as small-scale farms (SC) utilizing agricultural by-products mixed with complete feed, semi-extensive scale (SE) using flow-through (pond combined with concrete tanks) with good quality feed, or intensive scale (IS) using recirculation systems. It is possible in principle that the genetic gains achieved in the selection environment will not be fully realized in these diverse production systems. In other words, there is a possibility of a genotype by environment interaction (G×E) on performance of African catfish. We considered three main farming systems: small scale (SC), semi-extensive (SE) and intensive scale (IS). Since the SC system is close to the pond environment, the G×E effect is likely insignificant. In this case, we assumed that the genetic correlation between trait expressions between the two environments was 0.9. On the other hand, there is likely moderate G×E effect between pond and semi-extensive system, and significant G×E effect between pond and intensive scale. The genetic correlations of the same traits between these pair-wise environments assumed were 0.7 and 0.5, respectively. Selection index theory using the parameter values and pedigree information as described above was used in all simulation studies. The effects of G×E interaction on the underlying components of genetic gain are given in Table 3. The magnitude of G×E had strong effect on accuracy of selection (r_{IH}) and standard deviations of the index (σ_I). Changes in the genetic gain for all traits were proportional to the decrease in the magnitude of the genetic correlation from 1.0 to 0.5. Decrease in accuracy of selection and in standard deviation of indices was the main source of loss in genetic gain.

Despite the loss of genetic gain shown in Table 3, a single breeding program under standard pond environment is recommended for African catfish. A separate program for each environment is entirely infeasible in developing countries where resources and experience are limited. We made a very conservative assumption that there were large effects of G×E interaction. However, results from the literature across several aquaculture species indicate that G×E interaction is not of biological importance for body performance, with the genetic correlation estimates for the same traits under a range of environments studied all close to unity (Ponzoni et al. 2005; Fishback et al. 2002; Kause et al. 2003; Gitterle et al. 2005; Swan et al. 2007). In practical breeding schemes, a number of strategies can be applied in order to minimize G×E effects. For instance, recording performance of relatives of selection candidates in production environment to be jointly analyzed with the nucleus data may assist in the management of G×E effects.

CROSSBREEDING

Crossbreeding and hybridization are applied to utilize heterosis or complementary effect. Heterosis is the superiority in performance of offspring over the average for their parents. It is shown mainly in lowly heritable traits (e.g. survival rate, reproductive traits). Complementarity is the combination of favorable characteristics from parental lines involved in crossings. For African catfish, a typical example is the interspecific hybridization between *Clarias gariepinus* male and *Clarias macrocephallus* female. The hybrid shows better flesh quality and disease resistance than their parents, and makes up approximately 90% of catfish production in Thailand. Thai farmers favor culturing the hybrid due to their higher market price and higher efficiency of production. In Bangladesh, the *Clarias gariepinus* × *Clarias batrachus* hybrid also gives better hatching rate and survival than the pure parents, although the reciprocal cross is sterile or has a high mortality during nursing (Khan et al. 2002).

In addition, intergeneric hybridization between *Clarias gariepinus* and *Heterobranchus longifilis* has been used to improve growth performance and carcass yield (Hecht and Lublinkhof 1985; Legendre et al. 1992; Teugels et al. 1992; Nwadukwe 1995). The hybrid was thought to be sterile, although it has been recently shown to have the capacity to interbreed with wild *Clarias gariepinus* (see Brummett, in this volume). Further, the fish exhibit aggressive behavior and large variation in body weight (Fleuren, in this volume), and reduced immunity leading to high susceptibility to *Henneguya* infections relative to pure parents (Euzet and Pariselle, 1996).

Neither interspecific nor intergeneric hybridization appear to have been systematically studied in African catfish. For instance, the level of heterosis for economically important traits is still not known with certainty. If the heterosis advantages were small or negligible in this species, it would not be necessary to waste time in developing crossing systems. This is because culture of hybrids has raised concerns regarding the introgression of *Clarias gariepinus* genes into local or wild fish which may have effects on genetic integrity of native species. On the other hand, if the level of heterosis were significant, different breeding objectives could be defined to develop specialized lines for alternative crossbreeding systems. One example would be to develop a fast growth and high survival

Table 3: Genetic gain per year (Δ_G) for each trait, standard deviation of the index (σI), accuracy of selection (r_{IH}) and overall gain in economic units

Genotype by environment interaction	Direct responses			Correlated responses			σ_I ($)	Accuracy of selection	Δ_G in economic units ($)
	BW (g)	SR (%)	FI (g)	BW (g)	SR (%)	FI (g)			
R_g = 0.9	63.5	5.2	111.4	57.2	4.9	100.2	55.0	0.30	94.7
R_g = 0.7	63.5	5.2	111.4	44.5	3.6	77.9	41.6	0.23	71.6
R_g = 0.5	63.5	5.2	111.4	31.8	2.6	55.7	29.9	0.16	51.4

line, and a separate line selected to reduce competition effect or aggressiveness in *Clarias gariepinus*. The resultant crossbreds of the two lines combining advantageous characteristics of their parents would be used in commercial production. This overall approach has worked well with several animal species, but has been completely neglected in fish. Note, however, that running multiple breeding programs to develop specialized strains requires a high level of investment and management. In summary, the area of crossbreeding and hybridization in African catfish deserves further study to enable the design of proper breeding strategies for this species under the practical conditions of African countries.

SEX REVERSAL AND CHROMOSOME MANIPULATION

In African catfish, sex reversal to produce monosex male population by using the hormone (17 α-méthyltestoterone) is not effective (Pongthana 2001). Chromosome research in this species included meiogynogenesis (Volckaert et al. 1994) or mitogynogenesis (Varadi et al. 1999). By applying physical shocks (either cold or heat) to produce diploids, the success rate is relatively high regarding survival and hatchability (up to 81%, Varadi et al. 1999). However, a considerable amount of residual heterozygosity is still found, that is, the gynogenes are not fully homozygous (Galbusera et al. 2000). In these studies, the survival rate and the growth rate were always lower for the gynogenetic individuals than for their parents.

Gynogenesis is also applied to produce sterile polyploids with higher growth performance or higher fillet proportion. Different forms of polyploidy such as triploids (Henken et al. 1987), tetraploids (Varadi et al. 1999) and triploid hybrids (Na-Nakorn et al. 2004) can be successfully produced. However, there are no advantages in performance of triploids over diploids in African catfish (Henken et al. 1987; Na-Nakorn et al. 2004). In other fish species, growth of the triploids is variable, even lower than the diploids (reviewed by Dunham 2004, and Rasmussen and Morrissey 2007).

Until now, chromosome manipulation has been found to serve mainly for research purposes, namely generating inbred lines for genomic studies (linkage mapping, study of gene expression) (reviewed by Komen and Thorgaard 2007) or for applications in genetic conservation and protection of genetic diversity of native populations (Dunham 2004; Rasmussen and Morrissey 2007). So far, there have not been any types of polyploids of African catfish cultured under either small or large scale in any country, even with popular food species such as tilapia or salmon. The most widely used application of chromosome manipulation has been in bivalve shellfish, in particular triploid oysters. It is obvious that investment in research and development of gynogenesis techniques for African catfish needs justification from an economic viewpoint. In addition, there are still technical constraints associated with the techniques and their ease of application. However, they may be useful in the multiplication phase if production systems show biological and economic benefits from the culture of single sex or sterile populations, but there has been a lack of commercial protocols for practical production. The technique depends greatly on laboratory work, which may not be perceived as a readily available service providing a potential solution in the context of African countries. If resources and funding were available, such research could be encouraged to be carried out in universities or research institutions to further refine the techniques. Given that funding is often limiting, it would seem wise to invest in activities that can result in rapid and sustainable improvement in quality and performance of the fish in order to meet basic protein demand of poor people (e.g., selective breeding). The economic benefit from the genetic improvement programs in aquaculture species is substantial. They could make a significant contribution to the national economy and to food security in developing countries.

POTENTIAL APPLICATION OF MOLECULAR INFORMATION AND REPRODUCTION TECHNOLOGIES

MOLECULAR GENETICS AND MARKER ASSISTED SELECTION

Molecular research in African catfish has so far focused on genetic characterization, by using different markers (mainly allozymes and recently microsatellites) to estimate frequency of alternative alleles, level of heterozygosity and to measure genetic distance between domesticated and wild populations (Van der Bank et al. 1992), between genera *Clarias gariepinus vs. Heterobranchus longifilis* (Teugels et al. 1992) or between species *Clarias gariepinus vs. C. anguilaris, C. batrachus* or *C. macrocephalus* (Agnese et al. 1997; Na-Nakorn et al. 2002; Mohindra et al. 2007). In 2002, Kovasc and coauthors reported two sex-linked loci in males of African catfish which can be useful for early sexing of the fish. Sennan et al. (2004) also investigated potential impacts of introgressive hybridization of African catfish on their local Asian walking catfish *Clarias macrocephalus*.

We conducted a thorough literature search through different databases, but could not find any genetic linkage or physical maps in African catfish. There have not been any quantitative trait loci (QTLs) or genes with major effects detected in this species. At the present time, molecular genetics research in African catfish is still very limited, and far behind other aquatic species or farm animals. However, available markers have two possible applications: using genetic markers for population analysis, and using DNA fingerprinting for genetic tagging. Firstly, genetic characterization of strains could be useful to identify potential candidate populations before establishing a base population for the later conduct of a genetic improvement program. Due to the usual constraints with physical facilities, not all available strains or populations can be accommodated in breeding programs. Marker analysis can help to identify genetically distinct populations. The second possibility is the application of DNA tagging. Parentage testing and pedigree verification has four main advantages: increasing the number of families tested without the need for increasing tanks and ponds, reducing effects common to full-sibs, shortening generation interval, and consequently increasing genetic gain. Both experimental and theoretical results show that with the availability of microsatellite markers, pedigree analysis can give very high degree of accuracy across aquatic species. However, the technology is still very expensive, the cost of genotyping from $10-20[1] per sample ($2-3 per microsatellite). Therefore, we need to carry out cost-benefit analysis before including the technology in genetic improvement programs. Also note that genetic tagging cannot completely replace physical tags because the animals still need to be physically tagged for identification, genetic evaluation and selection.

We may assume that in the near future there will be: 1) a fully pedigreed breeding program firmly established in *Clarias gariepinus*, and 2) molecular information such as linkage mappings, QTLs or genes of known effect in important traits in this species. There are two main types of markers: direct and linked markers. Corresponding to each type of marker, there are different methods of selection. To the best of our knowledge, we have not found reports on any functional mutations or candidate genes controlling economically important traits in aquatic species. Therefore, at this stage, there is no opportunity for direct gene assisted selection or introgression assisted selection. With linked markers, there are two possible methods of selection: marker-assisted selection in crossed populations between inbred lines, and marker-assisted selection within strains (Dekkers 2004). For each method, three strategies can be applied, namely: 1) selection based on molecular score alone, 2) tandem selection: selection on molecular markers and then selection on estimated breeding values (EBV), and 3) index selection combining the two methods. In a simulation study, Zhang and Smith (1992) compared three different selection strategies and found that genetic gain is

1 All figures given in $ refer to US dollars.

highest for index selection combining both polygenic EBV and quantitative trait loci EBV. It is followed by best linear unbiased prediction (BLUP) selection and it is lowest for selection based on markers alone. For marker-assisted selection within strains, its efficiency depends on four parameters: type of trait measurements, level of heritability, size of QTL effects, and recombination rate (Meuwissen and Goddard 1996). In short, marker assisted selection (MAS) is beneficial for traits which are difficult to measure (e.g. flesh quality) and for traits with low heritability (disease resistance). In summary, with the current stage of development there are both technical and economic limitations in order to apply effectively MAS in practical breeding programs. There is a general consensus that investments in molecular research have been large, but that by contrast benefits have been generally small.

Recently, there have been two key developments. The sequencing of livestock genome leads to the discovery of thousands of single nucleotide polymorphism (SNP), and the cost of genotyping per SNP is therefore significantly reduced, only 1-10 cents compared with 2-3 dollars per microsatellite marker. This is opening possibilities for genomic selection. Meuwissen et al. (2001) were the first to propose genomic selection (GS). In principle, genomic selection predicts breeding values for a large number of haplotypes across the entire genome. It is equivalent to the BLUP method, but with the relationship matrix estimated from markers. Simulation studies showed that GS can increase response two-fold and reduce the cost of breeding programs, especially in dairy cattle where progeny testing is long and expensive (Schaeffer 2006). The efficiency of genomic selection is high. The correlation between genomic EBV and pedigree EBV ranges from 0.64 to 0.94, depending on the characteristics of the traits in question. It also depends on the number of SNP, linkage disequilibrium between QTL and markers, marker allele frequencies. One question is: how many SNP are needed to apply GS? Studies show that approximately 30,000 SNP are required for GS within strain or population and 50,000 SNP for GS across populations (e.g. Hayes et al. 2006). In a recent review, Kadarmidden and Reverter (2007) mention that genetic evaluation of about 100,000 SNPs is approximately equivalent to one based on infinitesimal gene model theory. The application of GS in practical breeding programs has started for dairy cattle in Australia, with 15,000 SNP (Tier et al. 2007). In New Zealand and the Netherlands, GS has also been initiated in dairy cattle and broilers. The potential value of GS in fish is still to be ascertained.

REPRODUCTIVE TECHNOLOGIES

We consider two possible reproductive technologies: in-vitro fertilization and cryopreservation. In-vitro fertilization (IVF) has two main advantages, although stripping sperm in males of African catfish is still impossible. IVF allows the design of different mating schemes, and the management of inbreeding accumulation. One example is factorial mating which mainly consists of four designs: complete, incomplete, factorial by set and rectangular mating. Benefits of factorial mating include: 1) increased accuracy of parameter estimation and thus accuracy of selection and, 2) reduced inbreeding. This may have been because factorial matings, when compared with the nested design, increase the number of half-sib families and decrease number of full-sib families, thus reducing the risk of selecting many individuals from the same parents (Sørensen et al. 2005). A number of theoretical studies (e.g. Dupont-Nivet et al. 2006) show that given the same effective population size (*Ne*), factorial matings can result in greater genetic gain and lower inbreeding than hierarchical nested and single pair matings.

Since the 1980s cryopreservation of milt has been successful in African catfish. Cryo-preservation of milt can play an important role in a pyramid breeding structure. In selection programs at the nucleus level, cryopreserved milt may be used as a control to measure genetic gain with minimum bias. This is mainly because the frozen sperm can present a wider genetic base than a random unselected control of limited size and there is no accumulative genetic drift over time. Furthermore, cryopreserved milt can be tactically used between year classes to reduce the risk of inbreeding in the selected population. In the future, once large scale genetic evaluation is underway, cryopreserved sperm can be used to create genetic connectedness between populations. Moreover, the establishment of a gene bank of cryopreserved milt would be useful for the conservation of genetic resources. However, there are also technical difficulties with male catfish; the collection and storage of sperm are still difficult. A few studies using cryopreserved sperm for artificial fertilization also reported malformed larvae (Horvath and Urbanyi 2000; Miskolczi et al. 2005). Therefore, there is a need to refine the techniques before widespread application.

DISSEMINATION OF IMPROVED FISH

Currently, the development of catfish production in Africa has taken place in the absence of any formal breeding structure. Among nine African countries that participated in the workshop on "The development of a genetic improvement program for *Clarias gariepinus*", two thirds do not have any breeding centers or research stations where a genetic improvement could be immediately initiated for this species. In all countries, there are only a few private hatcheries with limited capacity for producing and supplying adequate quantity and good quality fry to local farmers. Fry and fingerling prices are generally high in many countries (ranging from $0.1–0.2 per piece of 5-10 g). Most farmers are not able to afford or are not willing to buy due to concerns over fish quality. A widely observed phenomenon is that hatcheries produce fry from only a small number of brook stock, and the breeders are usually kept over a very long period (5 to 10 years). Due to poor management and maintenance, the quality of brood stock has deteriorated. In addition, generally there are no brood stock replacement schemes in place, and when there are, the replacement rate is very low (mainly from on-farm stock). These factors may be largely responsible for the poor performance of the fish, as observed in several systems of catfish farming in African countries. As a consequence of the poor management in hatcheries, the accumulation of inbreeding (with its associated negative effects) is inevitable. Furthermore, sourcing brood stock from grow-out ponds rather than from the wild, and the resulting high levels of inbreeding accumulated over time is believed to be one of the main reasons for growth decline in this species (e.g., in Uganda). The common practice of selecting brood stock based on its readiness to spawn may also lead to a loss of performance as the practice exerts an indirect negative effect on weight at harvest. The conclusion from this state of events is that there is a clear need, in parallel with the genetic improvement at the top of the pyramid breeding structure, to establish a network of public-private hatcheries. The hatcheries should specialize in the multiplication of the improved stock under strict technical protocols provided by local governments and international agencies (e.g. WorldFish) to ensure that high quality seed stock reaches the farmers and producers in their respective countries. Ponzoni (2006) and Nguyen and Ponzoni (2006) discuss strategies for effective dissemination of improved fish strains.

We again stress that genetic improvement is not particularly useful by itself unless the improved fish are disseminated to farmers and producers. Our earlier study indicated that the economic benefit from a genetic improvement program depends greatly on the adoption rates of improved fish by the industry and the dissemination rate to farmers. Based on the same approach, the economic benefit from the genetic improvement program in African countries (using Nigeria as an example) would be from $7.6, $23.8 and $48.1 million, corresponding to adoption rates of 10, 30 and 60%, respectively (Figure 1). The calculations are based on the total current production of 25,000 t in Nigeria in 2006 (Williams et al. in this volume), and a market weight of the fish of 1 kg, with the average price across African countries of $3.0 per kilogram of live fish. The dissemination of improved fish to the industry is a complex issue requiring tremendous efforts from local governments in terms of capacity building of the extension network, hands-on training of farmers, development of credit systems, social and economic policies as well as marketing systems for agricultural products.

CONCLUSION

It is concluded that investment in the genetic improvement programs for *Clarias gariepinus* can result in substantial economic benefits contributing to the national economy of African countries. The minimum benefit to cost ratio is approximately 15:1, corresponding to an economic benefit of at least $7.6 million. The efficiency of the breeding programs is also dependent on various biological, economic, environmental and operational factors. Technical risks due to deviations from theoretical predictions are low unless matters out of human control arise during the practical implementation of the program. However, the success of the program would require concerted efforts from international organizations, local governments and other relevant agencies. Capacity building of local staff and institutions is another area of priority. The establishment of strong linkages among governments and research institutions would facilitate the effective dissemination of improved fish to countries in the region.

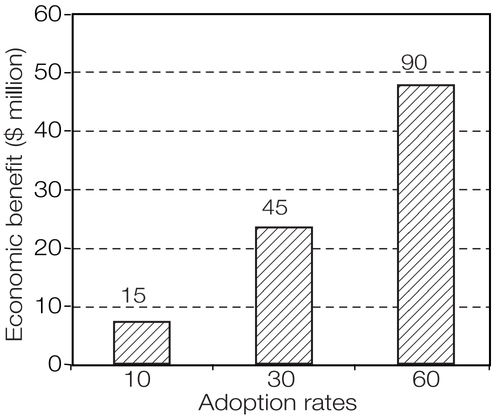

Figure 1: Economic benefit and benefit to cost ratio (at top of the bar) corresponding to different adoption rates of improved fish by the industry

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ANNEX A
WORKSHOP ON THE DEVELOPMENT OF A GENETIC IMPROVEMENT PROGRAM FOR CATFISH – *CLARIAS GARIEPINUS*

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ANNEX B
WORKSHOP ON THE DEVELOPMENT OF A GENETIC IMPROVEMENT PROGRAM FOR CATFISH – *CLARIAS GARIEPINUS*

Miklin Hotel, Accra, Ghana
5th to 9th November 2007

Workshop Program

4th November Arrival of participants

Day 1 ~ 5th November (Monday)

0800 - 0900	Registration	
0900 - 0930	Welcome Address	Dr. Yaw Opoku Ankomah
0930 - 0945	Introduction to the workshop, housekeeping rules	Dr. Raul Ponzoni
0945 - 1000	Coffee/tea break	
1000 - 1030	Country report: Ghana	
1030 - 1100	Country report: Kenya	
1100 - 1130	Country report: Malawi	
1130 - 1200	Country report: Namibia	
1200 - 1330	Lunch	
1400 - 1430		
1430 - 1500		
1500 - 1515	Coffee/tea break	
1515 - 1545	Nigeria	
1545 - 1615	South Africa	
1615 - 1645	Uganda	
	Catfish – World distribution, taxonomy and biology of the species, conservation issues	Dr. Randall Brummett
1645 - 1715	Wrap up for the day	

Day 2 ~ 6th November (Tuesday)

0830 - 1000	Catfish reproductive management and grow out	Ir. Willy Fleuren
1000 - 1015	Coffee/tea break	
1015 - 1130	Catfish nutrition and feeds	Dr. Sheenan Harpaz
1130 - 1230	Clarias in aquaculture: pros and cons	Dr. Randall Brummett
1230 - 1330	Lunch	
1330 - 1500	The application of genetic principles to catfish genetic improvement programs	Dr. Raul Ponzoni
1500 - 1515	Coffee/tea break	
1515 - 1630	WorldFish's genetic improvement program in Abbassa, Egypt	Dr. Mahmoud Rezk
1630 - 1700	Catfish molecular genetics – state of the art	Dr. Nguyen Hong Nguyen
1700 - 1730	Wrap up for the day	Dr. Raul Ponzoni

Day 3 ~ 7th November (Wednesday)

Field trip

Day 4 ~ 8th November (Thursday)

0830 - 0900	Group work – Introduction and assignment to groups	Dr. Raul Ponzoni
0900 - 1000	Work in groups	
1000 - 1020	Coffee/tea break	
1020 - 1230	Work in groups	
1230 - 1330	Lunch	
1300 - 1530	Work in groups	
1530 - 1545	Coffee/tea break	
1545 - 1745	Presentation of outcomes from work in groups	

Day 5 ~ 9th November (Friday)

0830 - 1000	Presentation of unified report
1000 - 1020	Coffee/tea break
1020 - 1200	Final debate and refinement of recommendations
1200 - 1230	Close of workshop
1230 - 1400	Lunch
1400	Participants depart at their own convenience

ANNEX C
OPENING STATEMENT AND WELCOME ADDRESS FROM THE DIRECTOR GENERAL OF CSIR-WRE, DR. YAW OPOKU-ANKOMAH

Mr. Chairman, distinguished invited guests, members of the media, fellow scientists, ladies and gentlemen. It is with much pleasure that I make this opening statement at the Workshop on Development of a Genetic Improvement Program for Catfish – *Clarias gariepinus* scheduled from today, 5th to 9th November 2007 at the Miklin Hotel, Accra.

On behalf of the Director General and on my own behalf, it is my honor to welcome you all to the Council for Scientific and Industrial Research (CSIR) and, in particular, to its Water Research Institute (WRI). Mr. Chairman, permit me to make a few comments about the co-organizing Institute to our guests.

The CSIR-Water Research Institute (WRI) is one of 13 research institutions of the CSIR. (It was formed in 1996 by merging the erstwhile Institute of Aquatic Biology (IAB) and the Water Resources Research Institute (WRRI), both of the CSIR). The CSIR-WRI has the mandate to undertake research on all aspects of water resources of Ghana in order to provide scientific and technical information and services needed for the sustainable development, utilization and management of the resources in support of socioeconomic development of the country.

The long-term key objectives of the Institute are to:

- Generate information and provide services and appropriate technologies for the sustainable development of surface water resources of Ghana;
- Generate, process and disseminate information on the amount of potable water that can be abstracted from groundwater and the reliability of its recharge;
- Generate, process and disseminate water and wastewater quality information to end-users;
- Enhance public health status through sound environmental management and water pollution control strategies;
- Increase fish production through aquaculture development and sustainable management strategies in inland and coastal waters of Ghana; and
- Promote commercialization efforts and strengthen capacity through the provision of water resources information documentation and technical support services.

The objectives stated above are achieved through six technical divisions of WRI, namely: Surface Water Division; Ground Water Division; Environmental Chemistry Division; Environmental Biology and Health Division, Fishery Division, and Commercialization/Information Division (CID).

Mr. Chairman, the CSIR-WRI has a long history in the area of collaborative research with the WorldFish Center that dates back to the early eighties when it was known as the International Center for Living Aquatic Resources Management (ICLARM). In those days, CSIR-WRI was actively involved in the collection of tilapia germplasm for the famous research that resulted in the production of the fast-growing GIFT tilapia. This was followed by quantitative genetic work at the Aquaculture Research and Development Center (ARDEC), Akosombo, aimed at improving the growth rate of the local indigenous Nile tilapia (*Oreochromis niloticus*) under the auspices of the International Network on Genetics in Aquaculture (INGA). This collaborative work has been going on for the past seven years.

These research efforts are yielding great dividends for the socioeconomic development of the country. Mr. Chairman, I hope the current efforts will hasten the process of national developments.

I take this opportunity to express my deep appreciation and thanks to the WorldFish Center for this highly successful partnership. I would also like to thank the organizers for all the toil to get this workshop to a successful start. Mr. Chairman, distinguished guests, ladies and gentlemen, once again I welcome you to the workshop and wish you a successful and fruitful deliberation.

Thank you.

ANNEX D
SPEECH OF DR. KWAME BOA-AMONSEM, DIRECTOR OF WATER RESEARCH INSTITUTE

Director of CSIR-WRI, project coordinator, fellow scientists, invited participants,

I feel honored to have been invited to play a role in this all-important workshop. I wish to express my appreciation of the choice of Ghana as the venue for this workshop. It is evidence of the fact that the quality of work of fisheries scientists of the CSIR-Water Research Institute has caught the attention of the international scientific community. I salute the Director and scientists of the Institute.

In the face of dwindling fish resources from the sea and other water bodies, the real means of enhancing production levels is through fish farming. However, it is known that the quantity of fish produced per unit area of pond per cycle is about 2.5 tonnes/ha and has remained the same since 2002 (GPRS II, November, 2005). This trend indicates that technology available is not being adopted by our fish farmers, or that more incisive technology is required to improve the productivity of pond farming.

Distinguished participants, productivity of fish can be enhanced biologically by three principal means: genetics, nutrition and pond management. Of these, genetic improvement is the only means that is permanent, and can be passed on from generation to generation. Quantitative genetics is a very powerful tool in breed improvement that has been used successfully to reduce the maturity period of broiler chickens from 18 weeks to 6 weeks. In this regards, the achievement of Dr. Attipoe´s team at the Water Research Institute in the improvement of Nile tilapia has been documented in “Agricultural Technologies 2001-2006” published by CSIR. It certainly will enhance the competitiveness of the industry in Ghana.

It is reassuring to note that this workshop seeks to extend the application of quantitative genetic theory to improve catfish, which will give fish farming a further boost.

Judging from the program details of this workshop, I have no doubt that this is going to be a very productive week. I wish you well and may God bless your efforts.

Thank you.

ANNEX E
FORMAT FOR GROUP DISCUSSIONS AND PRESENTATION

The discussion groups are supposed to identify the problems and the actions to be taken to address them. The discussions should culminate in recommendations regarding proposed work. These recommendations will then be used to persuade donors and governments about the worthiness of the work to be undertaken.

PROPOSED FORMAT:

OBJECTIVES

Statement of purpose (i.e. what the project aims to do, how things will change as a result of the project). What this project specifically will do; we need two or three statements that let the listener or reader know precisely what this project is about, so that he or she can decide whether the project is worthwhile.

THE PROBLEM

What is the problem we are addressing? Briefly describe the problem to be addressed, its nature, its importance, the size of the problem, and general questions that will guide the research, development and technology transfer process. The size relates to relevance and magnitude of the problem globally or regionally. Give an indication of what has been done to address the problem, if anything (e.g., other projects, approaches, studies that have also identified this as an issue). If nothing or very little has been done, say so.

JUSTIFICATION AND OUTPUTS

How will this project contribute to solving the problem? Why is this project necessary or important? To whom is it important? How will the countries involved benefit as a result of the project? What is the demand for this project? (Ideally, this reflects demand expressed by the potential beneficiaries.) What original contribution do the proposed research, development and technology transfer make? What are the outcomes or outputs sought from conducting the project? In case there is already other work going on in this area, how does this project leverage existing work, in particular projects funded by investor organizations we may be targeting.

Note: The outputs are the results that the project seeks to achieve. Try to indicate outputs as a numbered list. The outputs should, as much as possible relate to “tangible products” (quantifiable, qualitative or verifiable) from the conduct of the research, development and technology transfer activities undertaken. Try to set milestones, but not just those that consist of reports, frameworks or plans; try to relate them to real work with water, animals and people.

APPROACH AND ACTIVITIES

The approach is the conceptualization of the activities to be conducted in the context of the research, development and technology transfer to be undertaken. This section should include a brief overview of the type of methodology to be employed. The kind of data that are required for successful implementation needs to be mentioned (e.g., number and nature of genetic improvement programs to be established, populations to be sampled to establish a base population for the genetic improvement program, choice of regions for on farm trials, number and size of hatcheries to be involved in the dissemination of the improved strain(s)). This gives an informed listener or reader an overview of the feasibility and likely cost of the project. Give a list of the specific activities that are likely to result in deliverables that will impact the potential beneficiaries. Some donors want budgets by activity area so that they can better match inputs to outputs. The activities should follow logically and their timing should be given (typically in months after project inception).

PROJECT LOCATION

Indicate where the research will be carried out (e.g., regions, countries, production systems). This is very important. It may be wise to initially establish a program in countries that are currently best placed to run it successfully, and gradually integrate other countries as the project evolves and capacity building progresses.

NEED FOR CAPACITY STRENGTHENING

Identify capacity building needs and ways to improve that capacity in the context of the present project (e.g., what exactly are we going to do, run training courses at various levels, how many field days, etc.). When collaborators (institutions) are involved, indicate what their contributions are. Major collaborators will include universities, advanced research institutes, NARS. Indicate the qualifications and appropriateness of collaborators to do this work, and how this project will strengthen the capacity of national and regional institutions to address this sort of problem.

BENEFICIARIES AND STRATEGY FOR IMPACT

How will the project ensure that outputs have impact, and who (beneficiaries) will benefit, when and how? How will the outputs of the project be disseminated to target beneficiaries? Distinguish between the immediate impact of research (end of project situation) and the longer-term result. What things beyond the project's control might prevent or enhance impact?

DURATION

Allocate the number of years. Perhaps define phases of implementation (e.g., establish the base population in an initial phase, initiate the selection program, survey hatcheries, plan on farm testing, whereas in a later phase we may be in a position to actually disseminate improved catfish, accredit hatcheries, and survey farmers using the improved fish).

BUDGET

Ideally, this section should reflect the total budget to implement the project, and should give an indication of the financing strategy. It should indicate what the total budget is, and what the contribution from each one of the participating partners will be, as well as what amount any particular donor is requested to fund. For the present purpose, we will not develop a detailed budget, but just an approximate round figure with limited breakdown into components.

ANNEX F
CONCEPT NOTE

INCREASING FOOD PRODUCTION AND ENHANCING NUTRITION SECURITY IN AFRICA THROUGH THE DEVELOPMENT AND DISTRIBUTION OF IMPROVED AFRICAN CATFISH (*CLARIAS GARIEPINUS*) STRAINS

EXECUTIVE SUMMARY

From an estimated 542 million, the population of sub-Saharan Africa (SSA) is projected to increase to 852 million in 2015 and to 1143 million in 2030. Meeting the food and livelihood requirements of a population growing at such a rate poses significant challenges to all SSA countries, where virtually no progress has been made in recent decades in relation to increasing food consumption per head or in poverty alleviation in general. Nevertheless, Africa has a great potential for aquaculture development, with about 40 per cent of its surface area suitable for some form of fish farming. The majority of SSA countries have identified aquaculture as a means of increasing food production and alleviating poverty, but with the exception of Nigeria, production remains low in all of them. Catfish are native to Africa; they are widely sought after as food by the population and constitute a very valuable source of protein. The development of improved catfish strains and the application of "best practice" aquaculture techniques that are compatible with available resources and sustainable over time can result in 70 percent increases in production.

The government departments responsible for primary production in the countries selected for this project have identified aquaculture development as one of the means of ensuring food security in sectors of the population. Catfish were chosen as the preferred species for the present project. They have a number of attributes that make them especially suitable for culture (hardiness, flexible feeding habit and requirements, potential to produce two crops per year, ability to be raised in poly-culture) and they are highly accepted fish among consumers. The most salient project outputs will be:

1. National selective breeding programs for the production of high quality catfish seed consolidated or established in the participating countries.
2. Multiplication and dissemination strategies for the improved strains developed and implemented through both government and private hatcheries as deemed appropriate in each specific circumstance.
3. Workshops and training sessions for capacity building of NARS' staff, private hatchery operators and farmers.
4. Enhanced capacity in the government and private sectors to produce, distribute and utilize improved catfish strains as well as other aquaculture species of interest.
5. Increased food production due to better aquaculture practices and use of improved strains.
6. Impact on nutritional status and income of target groups.

The present project will build and capitalize on an earlier one called "Transfer of selective breeding technology for aquaculture improvement from Asia to sub-Saharan Africa and Egypt – Phases I and II", funded by the Japanese Human Resources Development Fund through the UNDP Special Unit for South to South Cooperation. The models developed and experience accumulated in the areas of genetic improvement and distribution of improved seed in Ghana and Malawi will be applied to catfish in Cameroon, Egypt, Ghana, Kenya, Malawi, Nigeria and Uganda, in what will be an example of South to South cooperation.

The WorldFish Center has a successful track record in the areas of developing improved strains of fish (Genetically Improved Farmed Tilapia, GIFT project) and of aquaculture production projects (Integrated Agriculture-

Aquaculture, IAA). Furthermore, its staff members are well recognized worldwide for their achievements in the field.

The project will be carried out over a period of five years. The total project cost has been estimated at US$1.0 to 1.3 million per breeding center established.

THE PROBLEM

Wild capture fisheries are dwindling, leading to economic declines in fishing communities and rapidly increasing scarcity of fish for human consumption. In general, rural communities are poor and need alternatives to diversify their economy as a means to reduce poverty and increase the quantity and enhance the quality of local food supplies. Aquaculture has been shown to be capable of directly addressing these problems, but it is widely constrained by the lack of high quality fingerlings, the problem that is exacerbated by weak national aquaculture research, development and extension programs. There are no African catfish improved strains available at present, and cultured stock exhibits low productivity quite likely due to inbreeding.

OBJECTIVES

GENERAL

- To improve the availability of high-quality catfish seed to fish farmers
- To build local capacity at the levels of producer, hatchery manager and NARES technical staff in the area of genetic resource management

SPECIFIC OBJECTIVES:

- Develop improved strains of catfish with characteristics of increased growth rate to market size and improved survival in culture; in future, the improvement of other traits such as disease resistance and temperature tolerance, may also be pursued
- Improve on-farm and hatchery brood stock management to eliminate problems due to inbreeding and to poor management of the genetic resource
- Improve the access to knowledge about brood stock management to farmers
- Strengthen regional inter-center collaboration and capacity in fish genetic resource management

JUSTIFICATION AND OUTPUTS

Aquaculture offers an option to increase food production. In a number of countries, it is already having a strong positive impact on economic growth and food security. In much of Africa, aquaculture in general and catfish farming in particular, has a recognized potential to generate revenues, create jobs, diversify local economies and increase local, national and regional fish supplies. Demonstrated successes in Egypt and Nigeria have resulted in profitable technological models (e.g. market weights of 600-700 g in 6 months; 1.5 kg in 12-15 months), and developed a pool of trained technicians within the region. However, productivity and profitability are compromised by a lack of high quality seed and of adequate feeds at an affordable price, and by limited market development and processing facilities. With up to 40 percent declines in the growth rate attributable to poor genetic quality of farmed stocks, the supply of high quality fingerlings has been prioritized as one of the key constraints to aquaculture expansion in most countries.

***C. gariepinus* production in West/Central (W/C) and East/Southern (E/S) Africa (FAO 2005); fr = Francophone, gb = Anglophone**

Country	Sub-Region	MT	1000 USD
Benin*	W/C (fr)	30	68.4
Burkina Faso	W/C (fr)	1	1
Cameroon*	W/C (fr/gb)	110	313.5
D.R. Congo	W/C (fr)	6	21
Ghana*	W/C (gb)	1,510	2,416
Kenya**	E/S (gb)	318	1,052.6
Malawi*	E/S (gb)	21	27.3
Mali*	W/C (fr)	300	300
Nigeria**	W/C (gb)	20,413	65,321.6
Rwanda	E/S (gb)	16	17.3
South Africa*	E/S (gb)	100	252.2
Zimbabwe	E/S (gb)	2	4
Total		**22,827**	**69,794.9**

* high priority countries, ** sub-regional centers

Nevertheless, existing government efforts to create a facilitating environment to alleviate this problem are not addressing key relevant issues in the improvement of the genetic quality of the stocks being farmed. Considering: 1) the wide indigenous distribution of catfish (hence avoiding the risks associated with the introduction of alien species), 2) that most national programs are lacking in capacity in selective breeding and genetic resource management, and that 3) expertise is available in Egypt and Nigeria, a regional approach appears as most appropriate for addressing problems of genetic quality of farmed catfish stocks.

OUTPUTS

- Up to three sub-regional catfish genetic improvement programs with at least one strain each available for distribution to the private sector
- Approximately 20 percent improvement in catfish supplies for human consumption in the short term
- Proportional growth in revenues, employment and productivity throughout the aquaculture value chain, including producers, transporters, wholesalers, retailers, feed producers and processors
- Strengthened capacity in the management of genetic resources among producers, hatchery managers and NARES.

APPROACH AND ACTIVITIES

Sub-regional breeding centers (in West/Central, Eastern and Southern Africa) linked to a research and training facility at Abbassa (Egypt) in North Africa, will establish and implement genetic improvement programs to develop one or more improved lines of *Clarias gariepinus* for use within each sub-region. Effective seed multiplication and distribution systems will be developed, national demand-driven Public-Private Partnerships (PPP) will be used to strengthen the brood stock management capacity of SME aquaculture investments, especially private hatcheries, through a series of national workshops, seminars and training courses.

ACTIVITIES

- Establish the physical infrastructure required to undertake selective breeding of catfish.
- Conduct regional training (taking advantage of existing expertise in Egypt, Nigeria and South Africa) to address human resource needs in selective breeding and brood stock management.
- Survey and characterize for both aquaculture and conservation purposes, available wild and farmed populations of *C. gariepinus*.
- Establish sub-regional brood fish populations for use in selective breeding.
- Determine, through research, appropriate breeding system methodology.
- Implement appropriate selective breeding programs for West-Central, Eastern and Southern Africa.
- Develop PPP training programs in major catfish producing countries in each sub-region to improve private sector hatchery capacity in brood stock management.
- Undertake a series of promotional activities on the use and management of improved seed, including a regional producers' symposium and trade show.

PROJECT IMPLEMENTATION

LOCATION

The project is envisioned to be implemented through a network of existing sub-regional centers. Egypt is seen as primarily a site for training and methodological research. The Nigerian private sector possesses considerable know-how on practical production technology. These two sources of expertise would be connected through training and capacity building to one or more sub-regional selective breeding centers from which improved brood stock would be developed and distributed throughout their respective sub-regions.

The WorldFish Regional Center for Aquaculture at Abbassa, Egypt is envisaged primarily as a training center and research site for the development of improved breeding technology for application at the other centers.

CAPACITY STRENGTHENING

While taking advantage of existing infrastructure as much as possible, upgrading, expanding and equipping basic breeding facilities will be necessary at the sub-regional breeding center(s).

Human resources within the region have to be substantially strengthened. Training is thus envisioned for: 1) selective breeding theory and methodology for senior NARES researchers at each sub-regional center; 2) catfish hatchery management and grow-out technology for breeding staff and technicians engaged directly in the sub-regional breeding programs, conducted in Nigeria; and 3) brood stock management for sub-regional outreach personnel conducted at sub-regional center(s).

Training in selective breeding approaches, monitoring and reporting will be conducted for two senior technicians at the WorldFish-Egypt center to build the human resources needed to implement the breeding programs.

Basic skills for catfish breeding go beyond brood stock management and breeding theory to include induced spawning, larval rearing, fingerling production and grow-out. Basing the selective breeding protocols on the prevailing production system(s) within the sub-region will help avoid problems of genotype by environment (GxE) interactions and ensure that improved strains can be easily adapted to the prevailing production systems. A training program in brood stock management and basic catfish production protocols for three project technicians from each sub-regional center will be conducted in Nigeria by WorldFish in close collaboration with Nigerian catfish farmers and NARES.

To enhance brood stock management skills outside the sub-regional centers and into farms throughout each sub-region, several training of trainers (TOT) programs will be conducted at the sub-regional centers (3 countries x 2 persons per country x 2 cycles = a total of 12).

These latter courses require a modest budget to develop the necessary base of expertise needed to train SME hatchery managers in each catfish producing country within the sub-region. Also, a series (usually 3 per year over 5 years = 15) of national seminars, on-farm trials, field-days and exchange visits will be conducted. This would create a favorable environment for the establishment of a good working arrangement with sub-regional private catfish hatcheries in Public-Private Partnerships (PPP) that can manage, disseminate and maintain the quality of improved seed obtained from the sub-regional breeding program.

PHASING IN, DURATION AND BUDGET

There are several options for phasing in the overall project implementation. There are indications, for example, that *C. gariepinus* populations vary to a certain extent over the total of their range and that in West-Central and East-Southern Africa different stocks are represented. It might then be reasonable to phase in the activities by sub-region. However, this will be dictated by the perceived urgency of the problem in each sub-region and the availability of funds.

In any case, the initial step is to establish well designed base populations, from which improved strains can be developed through selective breeding. As described in this concept note, capacity-building activities constitute an integral part of the project. Initially, activities will focus on the needs of national programs to begin and execute improved catfish genetic management at two key levels: 1) selective breeding on-station, and 2) brood stock management at local hatcheries.

Preliminary budget estimates indicate that the cost per breeding center for a five year project would be of the order of US$1.0 to 1.3 million.

BENEFICIARIES AND IMPACT

In order to solve a fundamental problem in regional aquaculture, replacing existing poor quality farmed stocks and improving brood stock management in farms and hatcheries are essential to benefit a broad range of players throughout the aquaculture value chain, including producers, transporters, wholesalers, retailers, feed producers and processors. Two areas of impact are foreseen:

1. Short term increases of 20-30 percent in growth rate based on improved brood stock management on existing hatcheries and vertically integrated farms, and
2. Longer-term, sustained improvements in fish farm productivity in the order of 50 to 60 percent based on the use of faster-growing strains of catfish.

Increases of this magnitude will raise regional catfish production by an estimated 20 thousand tonnes per annum with an approximate wholesale value of US$55 million only on existing farms. Increasing the competitiveness and economic attractiveness of catfish farming will encourage new entrants to fish farming. With about half of the retail value of the fish produced in aquaculture accruing to enterprises that are not directly involved in fish production, substantial increases in employment and income generation over the entire value chain are envisaged.

African catfish *(Clarias gariepinus)* production has gained considerable importance in a number of African countries. The species has several desirable attributes that make it attractive for aquaculture development. It is easy to reproduce, it does not require specialized feed, it tolerates high stocking densities, it accepts artificial feed, it tolerates poor water quality, and very importantly, it is highly sought after in local markets and economically viable in pond production systems. The species is endemic to Africa. In 2007 the WorldFish Center organized a workshop in Accra, Ghana, hosted by the Water Research Institute, to review the status of the catfish industry in Africa and develop recommendations on how best to approach the issue of genetic improvement programs. The results of the workshop are presented in this volume.

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