Biodiversity, Management and Utilization of West African Fishes

Edited by

Eddie K. Abban
Christine Marie V. Casal
Patrick Dugan
Thomas M. Falk

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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

Preface

Since 1997, the WorldFish Center (formerly known as ICLARM) currently headquartered in Malaysia, the CSIR-Water Research Institut (WRI) at Accra in Ghana, and the Univerity of Hamburg's Institut und Zoologisches Museum in Germany have carried out collaborative research on the biodiversity of tilapias in Africa, with special emphasis on the Black-chinned Tilapia, *Sarotherodon melanotheron*. Their efforts have been financially supported by the German Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklun (BMZ) through the German Agency for Technical Cooperation (GTZ).

As part of this cooperation, a workshop was convened in July 2002 at WRI, Accra to present major results of their recent efforts. One session of the workshop was devoted to a meeting of the West African Fisheries Association (WAFA). The combined event was called "Biodiversity, Management and Utilization of West African Fishes" with reference to the international genetics project under whose umbrella the WAFA functioned.

The present proceedings mainly contain extended abstracts of the papers delivered at the workshop, summaries of discussions, conclusions and recommendations, as well as a list of the participants. It is worth observing that the topics of most papers reflect the range of issues that need to be integrated in order to determine, document, conserve and utilize the biological diversity of this species. The presentations and discussions also show the limitations of knowledge on the species and thus the need for sustained research.

The Editors

Opening Statements

Statement from WRI

Dr. Charles A.Biney
Director

Mr. Chairman, Hon. Minister of Food and Agriculture, Distinguished Invited Guests, Colleague Scientists, Ladies and Gentlemen. It is with great pleasure that I make this statement at the opening ceremony of the Workshop on the Biodiversity, Management and Utilization of West African Fishes scheduled from 2 to 4 July 2002 in Accra.

On behalf of the Acting Director General, it is my honour to welcome you all to the Council for Scientific and Industrial Research (CSIR) of Ghana and in particular to its Water Research Institute (WRI). Mr. Chairman, Hon. Minister, permit me to say a few words about the host 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 the merging of 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 into all aspects of water resources of Ghana in order to provide scientific and technical information and services needed for sustainable development, utilization and management of the resources in support of socio-economic development of the country.

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

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

These objectives are achieved through six Technical Divisions of WRI, namely: Surface Water; Groundwater; Environmental Chemistry; Environmental Biology and Health, Fishery and Commercialisation cum Information Division.

Mr. Chairman, coming just after the celebration of our 5th Anniversary as a merged Institute of the CSIR, we in the Water Research Institute are proud to host this workshop attended by scientists from Africa, Asia and Europe.

I would like to use this opportunity to thank our collaborators, the WorldFish, the University of Hamburg and our donor GTZ (German Technical Cooperation) for the successful collaborative research. I would also like to thank the organizers for all the toil to get this workshop to a successful start. Mr. Chairman, Hon. Minister, once again, I welcome all of you to the CSIR-WRI and the workshop.

Thank you.

Statements from the University of Hamburg - ZIM (Zoologisches Institut und Museum)

Thomas M. Falk
Senior Scientist

Mr. Chairman, Ladies and Gentlemen.

On behalf of our institute it is my pleasure to welcome you all to our final project workshop here in Accra. During the next few days we are going to discuss some common interests in the biodiversity, management and utilization of West African fishes and we shall also try to identify future research and training priorities for this area. In fact, looking back, this is what we have been doing for some years and what we can call a continuation of a quite successful and also long-term collaboration.

Our partnership with WRI and the WorldFish Center on tilapia genetic resources research started in 1986 with a project called "Utilisation of Tilapia Genetic Resources for Aquaculture". Through the 1990s until today these partnerships in research and training have received constant support from the Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung (BMZ), Abteilung Gesellschaft für Technische Zusammenarbeit (GTZ) of the Federal Republic of Germany. The University of Hamburg greatly values these partnerships and is particularly grateful to BMZ/GTZ, Germany, for their generous and constant support.

After a successful finalization of the first project in 1989, four additional project periods, including two international project workshops, followed and now we are presently finalizing our research activities on the black-chinned tilapia complex. But apart from this, a variety of other research activities have been continued, covering other tilapia species, and including, for example, some African and South American characids. With regard to tilapias, our more recent studies have been focused on the black-chinned tilapia complex (*Sarotherodon melanotheron/Sarotherodon nigripinnis* spp.), on *Tilapia guineensis*, another major important lagoon tilapia in West Africa, the Nile tilapia (*Oreochromis niloticus*), and the Mango-tilapia (*Sarotherodon galilaeus*). We shall have a look at the results of these studies and their implications for fisheries, aquaculture and biodiversity conservation.

Besides genetic research activities, the project also initiated pilot studies on culture characteristics of tilapias, with the involvement of local communities to make them aware of the importance of small-scale culture of tilapias. And now the project is linked to an additional project, funded by the World Bank, that has recently been initiated by WRI and an NGO to focus on aquacultural approaches in Ghanaian lagoons. From this point of view I am very happy with the general intensions of our studies and activities.

Ladies and gentlemen, again, greetings from our University and thanks for coming.

Wolfgang Villwock
Project Leader at Hamburg

Honorable representatives of the Ghanaian Government, distinguished Director of the Water Research Institute, long-time Ghanaian partners, dear participants of the workshop, ladies and gentlemen.

Although medical advice recommended against my participating in this workshop, I hereby will take the opportunity to give my words of welcome and thanks to everybody joining this conference. They are especially directed to those who have been working with our institute for years. I wish to thank at this moment not only the Head of the Fisheries Department of WRI, Dr. Eddie Abban, but also the International Center for Living Aquatic Resources Management (ICLARM-The World Fish Center), represented here by Dr. Patrick Dugan. It is also a great pleasure for me to take the occasion to offer my sincere thanks to our long-term partner and personal friend of mine, Dr. Roger Pullin, a former program leader of the WorldFish Center, and WorldFish research associate, Christine Casal. In this context, I must not forget to remark upon our German mentors in the Division of International Agricultural Research of the GTZ, Dr. Martin Bilio and Dr. Stephan Krall. All of them cooperated at their best in guiding our common project to extend our knowledge on the biodiversity and management of African fish.

While thinking about the general targets and activities of the last 10 years or even more of cooperation with the team of Dr. Abban, I finally would like to thank Prof. Lothar Renwrantz and Dr. Thomas Falk (University of Hamburg).

To all of you and all other participants I wish a very successful meeting. Welcome again, and best regards to all of you.

Statement from the WorldFish Center

Patrick Dugan

Mr. Chairman, Honorable Minister, Ladies and Gentlemen.

It gives me great pleasure to be able to say a few words of welcome on behalf of the WorldFish Center. It is always a pleasure to be back in Ghana, but especially so to be here with a group of friends and colleagues dedicated to a common cause – the conservation and sustainable use of West African fish.

This meeting comes at an important time. Over the past six years the Water Research Institute, the University of Hamburg, and the WorldFish Center, with the support of BMZ and GTZ, have carried out an important program of research on the biodiversity and potential use of tilapias in West Africa. This week now gives us an important opportunity to review our achievements, assess progress, and look forward to what needs to be done in coming years.

For this reason the WorldFish Center attaches great importance to this workshop. Over the past 18 months the WorldFish Center has been undertaking a review and redesigning our program in Africa. This has re-emphasized the importance of working to sustain the region's capture fisheries, while developing the large potential for aquaculture. To help underpin these two objectives we need to improve our understanding of the fish biodiversity of the region and the requirements for its management and use.

It is in this wider regional context that this week's meeting is of special significance. By bringing together your expertise, reviewing progress in the collaborative work of WRI, UH, and WorldFish Center, we hope to be able to identify future priorities for research, training and management. We, therefore, look forward to the discussions over the next few days and to building upon the outcomes to improve management of fish in West Africa for the benefit of the people of the region.

Thank you.

Statement from GTZ

Dr. Uwe Lohmeyer

Participants of the workshop, I regret that I cannot personally attend the workshop, but I do not want to miss the opportunity to send you my regards as well as best wishes for the success of the international workshop on “Biodiversity, Management and Utilization of West African Fishes”.

This workshop is being convened to mark the end of a collaborative research project of the Water Research Institute, the University of Hamburg, the WorldFish Center and GTZ. GTZ highly appreciates the efforts made by this project for the conservation and sustainable use in capture and culture fisheries of brackish water tilapia which is widely exploited in the coastal zone of West Africa. The project, therefore, made an important contribution to secure fish supply and livelihood opportunities for fishers and farmers in this region. Furthermore, results and experiences of this project can be used in other regions as well as for other exploited or exploitable fishes.

The achievements of this project are of special significance for the conservation of genetic resources which are a key factor in long-term and sustainable food security and are presently under serious threat. Since conservation of aquatic resources has now become a global concern and aquatic biodiversity is beginning to attract the attention of policy makers, I am very optimistic that the results of this research project can provide valuable information for future programs geared at the conservation of genetic resources.

Thank you for giving me the opportunity to give this statement.

Statement from the Directorate of Fisheries, Ghana

Dr. Emilia Anang

Agriculture Director

Mr. Chairman, Hon. Minister of State, invited guests, fellow fish workers, ladies and gentlemen, I bring greetings and support from the Directorate of Fisheries of Ghana to this workshop.

The Directorate, which I am representing for the next few moments, is the mother fish institution in this country. As such, WRI, administratively, constitutes a technical arm of the Directorate. Mr. Chairman, I am pleased to proclaim that the theoretical administrative relationship between the Directorate and WRI has always been a practical reality. The two institutions have been collaborators and partners in several fisheries development activities including training and extension of technologies to fish farmers.

For example, the Directorate has been the main organization to extend the results of a phase of research related to Integrated Aquaculture-Agriculture, undertaken in this country by WRI. The same partners are involved in today’s workshop. So I may as well inform the WorldFish Center, the University of Hamburg and GTZ that the Fisheries Directorate is, therefore, a partner in these activities, though we have not met directly yet. However, we intend to improve this situation soon.

Mr. Chairman, ladies and gentlemen, the interest of the Directorate of Fisheries in this workshop is that we share similar concerns with WRI in ultimately improving fish and fisheries resources availability and utilization in this country although our main concerns are production and management. That is why we wish this workshop every success.

Thank you for your attention.

Opening Address from the Minister of Food and Agriculture, Ghana

Hon. Courage Quanshiga
Minister for Food and Agriculture

Mr. Chairman, Honorable Ambassadors of international and local research and development agencies, Director, Water Research Institute, international and local researchers, ladies and gentlemen with interest in fishes, good morning.

The background to this workshop indicated that four major national and international institutions, namely: The WorldFish Center, the University of Hamburg, Germany, CSIR-Water Research Institute, Ghana and the German Agency for Development (GTZ) have for many years collaborated to research on biodiversity of our fish resources in West Africa and Ghana in particular. Now you wish to share your results with interested institutions and find ways forward. I congratulate you for that length of collaboration, your desire to share and to look ahead to cooperate with even more partners in future.

I am pleased as always to be among people like you. This is because your activities in addition to expanding our knowledge on resources of nations, ultimately aim at enhancing the status of food security of our world. Ensuring food security in general is a charitable endeavor but in developing countries where population increases completely outstrip production capacities, it is also honourable. As the Minister for Food and Agriculture of this country, it is my responsibility to encourage all processes which eventually contribute to food availability. Therefore, your efforts make it my pleasure to be in your company to share in knowledge revealed by your research that could help me deliver on my job.

Fish is an important food commodity in tropical Africa generally as the major source of animal protein in diets of a majority of populations. In West Africa, issues surrounding fish also directly and indirectly influence the economic status of all the sub-regional countries. Thus for you to devote efforts and resources to investigating the diversity of the resource, which will present opportunities of expanding fish utilization, it is both honorable and humane.

It is common knowledge that the world's traditional sources of fish, that is, our marine, brackish and freshwater systems and fish communities have been and continue to be greatly abused by humans resulting in reduced availability of fish. Yet, by the nature of humans we continue to demand even more fish from the systems. The combined situation is highly pronounced in our part of the world, where insufficient knowledge of fish resources limits our basis for their management. This is compounded by easy degradation of their environments and wasteful over-exploitation.

Thank you for your efforts and your attention.

Session I

Biodiversity, Culture and Importance of Tilapias in West Africa

Chair: P. Dugan

Socio-Economic Importance of Tilapiine Fishes (Teleostei, Cichlidae)

E. K. Abban and S. Agyakwa
Water Research Institute, Accra, Ghana

T. M. Falk
Zoologisches Institut und Zoologisches Museum der Universität Hamburg,
Martin Luther King Pl. 3, 20146 Hamburg, Germany

The present day inland fish fauna of Africa is fairly diverse. This diversity is attributed to factors and events including: the tropical ecological characteristics of regions, diversity in inland fish habitats, history of diversification and extinctions, historical geographical and climatic events, and long term effects of human inflicted changes. The composition of African inland fishes broadly consist of two major groups: the non-cichlid fishes (about 3 000 species) and the cichlid fishes (about 870 species which includes the tilapias).

West Africa, comprising of about 15 countries, includes both coastal and land-locked countries which provide diverse inland fish environments. The major water systems providing fish habitats include the Niger, Volta, Bandama, Sassandra, Comoe, Pra and Gambia rivers. Annual Fish production records of West African countries provided to FAO annually show that inland fish production was about 389 319.0 tonnes in 1996. In every country, the three to five most commercially and thus socio-economically important inland fish taxa include tilapias. Estimates of tilapiine fish component of country productions can be averaged at 20%. There is also evidence that fish production records from Africa are under estimations (Abban 1999), which probably means about 20% of all attributes of inland fish in West Africa is due to tilapiine fishes. Diversity of tilapias in West Africa consist of 2 species of *Oreochromis*, 6 species of *Sarotherodon* and 14 species of *Tilapia* (Leveque, Paugy and Teugels 1992).

Socio-economic analysis of fisheries emphasizes production and availability. This is because fish provide the most available animal protein for many West African communities. It is also the commodity around which income generating activities of 2-5% of West African country populations revolve [e.g. (a) fishermen, fish

Table 1. Estimated Tilapia Production in W. African Countries.

Country	Inland Fisheries Production (tonnes) 1996	Tilapia Proportion (estimated at 20% of Inland Production)
1. Benin	35 000.0	7 000
2. Burkina Faso	7 500.0	1 500
3. Cote d'Ivoire	11 650.0	2 330
4. Gambia	2 500.0	500
5. Ghana	73 580.0	14 716
6. Guinea	4 000.0	800
7. G. Bissau	250.0	50
8. Liberia	4 000.0	800
9. Mali	111 910.0	22 382
10. Niger	4 135.0	827
11. Nigeria	67 794.0	13 558
12. Senegal	47 500.0	9 500
13. Sierra Leone	14 500.0	2 900
14. Togo	5 000.0	1 000
TOTAL	389 319.0	60 578

processors, fish transporters and traders, canoe builders, (b) fisheries inputs traders, e.g. nets, salt, outmotor spares etc.].

"Silent" socio-sconomic issues of tilapia require scientific and socio-economic research as their backbone. Demand outstrips capture production, therefore, culture and enhancement production are expected to play more important roles everywhere and tilapias are the first fish-culture candidates in West Africa.

Economic and social investments are required for infrastructure, capital items and human resource development to industrialize and increase cultured tilapia production which includes the development and establishment of hatcheries, feed plants, farms and the development of management systems.

Socio-economics of reducing waste from present and future production is also another issue. Storage and processing research and other involvements with consideration for indigenous technology also require research attention.

Socio-economics of expanding utilization of tilapia produced is another aspect where research can focus. Filleting of larger fish to allow use of by products in fish meal production involves reducing desire for whole fish on table.

An estimated US$40 million per year is spent on fisheries development in the 'region' (West Africa). Capital aid expenditure exceeding technical assistance by 3:1 - especially for industrial infrastructure, stocks assessment, fisheries management and artisanal fisheries development and training.

The lessons learnt from the past include: over-emphasis on government infrastructure, especially fish stations; the over-emphasis on technical issues to the exclusion of social and economic considerations; the lack of understanding of the fact that there is not one ideal culture system for all environments and procedures; the lack of recognition that most often poor or low yield was a result of poor management and the lack of appreciation of aquaculture as part of general agricultural enterprise.

Table 2. Direct aid to artisanal fisheries in West Africa 1977-1980 (in Millions of US$).

Direct aid to/at	'77	'78	'79	'80
artisanal fisheries (as of total)	17	16	12	11
country level	3.73	2.96	4.64	4.96

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Discussion

Dr. Falk: Are there any data on individual tilapia species so that we can look into their socio-economic impacts in West Africa in more detail?

***Dr. Abban*:** River systems have diverse ecosystems. For example, *O. niloticus* is important in inland water whereas *T. guineensis* is the most important species in brackish water/lagoon in West Africa. This was further corroborated by Prof. Ayinla, who said that the ecosystem is an important factor with regard to the economic prominence of each species, e.g. ecosystem restricted distribution of socio-economic important species.

Dr. Pullin: It would help policymakers to be able to estimate the production potential in West African waters. This was done on a broad scale by FAO using GIS (Water availability, climate, etc.). For agriculture potential, however, it would be useful to make ecological models of typical West African water bodies (using ECOPATH/ ECOSPACE/ECOSIM). These models are, however, only based on trophic levels and may lump together several species of say tilapia for example. At present these ecosystem models do not consider genetic variation among species and populations. This could be taken forward so as to assess better performing strains in aquaculture environments for example. This may be considered as a possible future development in ecological modelling, especially for aquaculture systems.

Dr. A. Diallo: Considering unconfirmed production characteristics of *S. melanotheron* compared to *O. niloticus*, is *S. melanotheron* a good culture candidate? In connection with the conservation of *S. melanotheron* diversity, what happened to the Genetic Center Project?

***Dr. Abban*:** If someone wished us to breed for salt tolerant *O. niloticus* for culture in brackish waters, I would suggest investigating alternative benefits in improving e.g. *S. melanotheron* for culture in other environments. This also limits the distribution and introduction of *O. niloticus* into environments where *O. niloticus* does not naturally exist. Regarding the Genetic Center Project for West Africa, the project currently is on hold but it can be revived during this workshop.

Dr. Dugan: I would like to pose a question to the representative of the Minister of Fisheries on the future demand for cultured fish in Ghana. The proximity of the coast of Ghana and the large supply of marine fish has probably been a reason why aquaculture has not been taken up so rapidly. What are future plans in the light of the changing socio- economic status for the possibility of utilizing these tilapias for aquaculture?

Hon. Dr. Antwi: The continued exploitation of our marine resources has definitely led to the decline in fisheries catch. In the past, people did not want to eat cultured fish, but one cannot tell the difference between tilapia which has been cultured from that which comes from freshwater lakes or lagoons. So, when the country picks up aquaculture properly, this will provide fish which we could not get from the sea or the lake and also relieve our sea and lake of heavy exploitation.

Genetic Tools for Assessing Fish Biodiversity and Assisting Culture Practices: An Overview

Jean-François Agnèse
IRD CNRS Laboratoire Génome Populations Intéractions
UMR5000, CC 63, Univ. Montpellier II
34 000 Montpellier, France

Genetic tools are being used to significantly increase production in world aquaculture as well as to conserve and protect fish biodiversity. Today there is a vast range of techniques used to describe genetic variation.

Since the '50s, karyotype studies have been used to characterize species by their chromosome set. It is important to aquaculture to know the ploidy levels and in some case to locate sexual chromosomes. Allozyme studies based on the biochemical properties of enzymes have been for long used to establish population structure based on allele frequencies, changes in space and time, inbreeding, outbreeding and dispersal, paternity studies, species boundaries, hybridization, etc. The total number of such studies has not decreased in recent years. This technique is relatively cheap and fast for analyzing single locus variation in natural and artificial populations of any living form. All other more recent molecular techniques are based on PCR (Polymerase Chain

Table 1. Genetic approaches for assessing fish biodiversity.

Application	Karyotypes*	Allozymes*	RFLPs	RAPDs	Microsatellites	AFLPs	Sequencing
sexual chrom.	+	-	-	-	-	-	-
species bound.	m	+	+	+	+	m	+
pop.subdivision	-	+	-	m	+	+	€
heterozygosity	-	+	+	+	+	+	€
paternity	-	m	m	m	+	+	m
relatedness	-	m	m	m	+	+	€
hybridization	+	+	-	+	+	+	m
gene mapping	+	-	-	-	m	+	-
geo. variation	-	+	+	m	+	m	€
phylogenies	-	+	+	-	-	-	+

- Techniques which use living specimens or fresh (frozen) tissues, all the others can use alcohol preserved material.
- + appropriate technique, - inappropriate technique, m moderately appropriate technique, € expensive technique.

Reaction). PCR is used to specifically amplify a part of the DNA, generally one gene or a part of it, in order to enable its analysis.

The RFLP (Restriction Fragment Length Polymorphisms), for example, is applying restriction enzymes (enzymes that cut DNA when they recognize specific short sequences) on PCR amplified fragments. Any mutation at the restriction sites would not allow the enzyme to cut the DNA or would create new restriction sites. RFLP is mainly used on mitochondrial DNA to characterize populations or to differentiate among species.

RAPD (Randomly Amplified Polymorphic DNA) consists of amplifying unknown DNA strands from crude DNA samples using short primer sequences that randomly adhere to different regions of the DNA. RAPD is used to characterize the level of genetic diversity or to recognize populations or species and does not need any previous knowledge concerning the species genome. This technique can thus easily be used on new species or populations. Nevertheless, this technique is sensitive with regard to the quality of DNA and results are not always easily reproducible.

A related method is AFLP (Amplified Fragment Length Polymorphism), where different strands of a DNA sample are cut with restriction enzymes before amplification. Applying this technique, the information is also provided in terms of banding patterns. This technique is very useful in gene mapping as well as population characterization.

Also used in gene mapping and population characterization is the study of microsatellites that are repeated short sequences with a very high mutational rate. Microsatellites are found in every part of the genome. They are also largely used for paternity analyses.

Sequencing is the ultimate technique and its technology has developed rapidly over the past two decades. The power of the technique has ensured that DNA sequencing is one of the most utilized molecular approaches for inferring phylogenies. Nonetheless, sequencing is labour intensive per individual and per locus examined, and other approaches are often more appropriate when many loci or individuals are required.

All these techniques are not equivalent and their application depends on the questions to be answered. One or more techniques are often suitable. Table 1 summarizes the value of the different techniques for different questions and problems to be addressed. All approaches provide interesting and important insights into biodiversity, conservation biology and aquaculture. It makes little sense to think of one technique as being inherently superior to another. Rather than promoting the latest technique as a panacea, it is worthwhile to consider which techniques are best suited for particular questions and problems.

Discussion

Mr. Kwarfo-Apegyah: You hinted that it seems to be difficult to apply the genetic tools to tropical fish species, could you explain why?

Dr. Agnese: All genetic tools can be successfully applied to tropical fish except perhaps cell culture for the establishment of karyotypes. The reason is not well known but it probably has something to do with the fact that less research has been done on tropical fish species than cold water fishes.

Prof. Ayinla: The presentation on the tools were quite clear and well presented. The application of these tools to the West African fish species is important for a better understanding of fish genetic resources with particular reference to tilapias. Human resource development for a better understanding and application of these tools are thus very important and urgent.

Dr. Pullin: FAO is currently building fish genetics component for its Fisheries Information Systems. The Standard Genetics terminology and query structures will have to be available in French as well as English and other major UN languages.

Session I: Summary and Conclusions

Dr. Abban's paper talked about the diversity of river systems and the importance of tilapia in the presence of this diversity. He stressed that *O. niloticus* is the most important species in the region. The overview of the importance of tilapias in West Africa shows the need for more detailed analysis on various issues/questions such as:

- To what extent is the picture of socio-economic importance that is presented true of all countries or systems in West Africa?

- What is the extent of variation in socio-economic importance among/within species in West Africa?

- What is the impact on species of changing environmental factors; are we able to think forward, say 5 – 10 years from now, to see the demand, threats etc. to fish biodiversity, especially tilapias, and then do research based on these in order to give better information to enhance sustainable management, utilization and conservation of tilapias (fish biodiversity)?

Dr. Agnese's paper elucidated various genetic tools for assessing fish biodiversity and assisting culture practices. The tools include those applicable to living specimens (karyotypes and allozymes) as well as those which can be applied to preserved specimens (RFLP, RAPD, AFLP, microsatellites). Both advantages and disadvantages of the different tools were discussed. It is, however, clear that not much work has been done on tropical fish species. This, therefore, calls for collaboration and meaningful partnerships between countries in the region on one hand and advanced research institutes in Europe and elsewhere on the other. The emphasis of partnerships and collaboration should emphasize human resource capacity building and strengthening of established laboratories in the region.

Session II

The Project and Related Subjects

Chair: Dr. R.Pullin

Genetic Diversity of West African Lagoon Tilapias and its Implications for Fisheries, Aquaculture and Biodiversity Conservation: Case Studies on *Sarotherodon melanotheron*, *Sarotherodon nigripinnis* and *Tilapia guineensis*

Thomas M. Falk
Zoologisches Institut und Zoologisches Museum der Universität Hamburg, Martin Luther King Pl. 3, 20146 Hamburg, Germany

Guy G. Teugels
Laboratory of Ichthyology, Africa Museum (MRAC), B-3080 Tervuren, Belgium and KULeuven,
Laboratory of Comparative Anatomy and Biodivertsity, B-3000 Leuven, Belgium

Eddie K. Abban
Water Research Institute, P.O. Box 38, Accra, Ghana

Aquatic biodiversity provides the genetic resources that are the basis for fisheries and aquaculture. However, despite some exceptions this diversity is still poorly documented, in particular at the intraspecific level and with regard to molecular genetic approaches. It is, however, becoming more widely accepted that such data sets may have essential impacts on the development of management and conservation strategies and the utilization of aquatic genetic resources. We summarize here our results from a variety of genetic studies on the major important lagoon tilapias in West Africa.

Since 1997, genetic characterizations of populations and strains of *Sarotherodon melanotheron*, *S. nigripinnis* and *Tilapia guineensis* have been undertaken in West Africa as part of two collaborative research programs financed by the German Agency for Technical Cooperation (BMZ/GTZ). Populations from various localities in Senegal, Sierra Leone, Liberia, Ivory Coast, Ghana, Togo, Benin, Gabon and Congo-Brazzaville were examined. Depending on the level of genetic differentiation, the availability of sample material and the questions to be addressed, different genetic markers were used [allozymes, globin chain variations, substitutional variations in aligned cytochrome b sequences (307 bp), variations in mtDNA control region sequences (403-405 bp), RAPDs (randomly amplified polymorphic DNA)]. The majority of markers were comparatively studied. The same materials were also analyzed morphologically.

We shall first focus on the most fundamental impact of our studies with regard to the management and conservation of aquatic biodiversity, namely the taxonomy and systematics of target species. Secondly, we shall demonstrate the importance of detailed information on the biogeography and recent history of these species and finally, we shall focus on the genetic diversity of populations.

Systematics

Several morphological and genetic studies focusing on allozyme variations have been conducted with respect to the systematics of the black-chinned tilapia complex (Trewavas 1983; Teugels and Hanssens 1995; Pouyaud and Agnèse 1995; Adépo-Gourène et al. 1998; Falk et al. 1999, 2000). Originally, only a single species, *S. melanotheron* (Rüppell, 1852) covering five subspecies was recognized by Trewavas (1983). However, subsequent morphometric and genetic analyses (Teugels and Hanssens 1995; Pouyaud and Agnèse 1995; Adépo-Gourène et al. 1998; Falk et al. 1999) seriously questioned the validity of some of these taxa.

As part of this project, new material from 34 populations (635 specimens) from all over the distribution range of the black-chinned tilapia complex has recently been examined. As a major important result of these studies two polymorphic and geographically distinct species are recognised (Fig. 1a). (1) *S. melanotheron* (Rüppell, 1852) found along the coast from Senegal to Cameroon, and (2) *S. nigripinnis* (Guichenot in Dumeril, 1859) present from Gabon to the mouth of the Congo River. Both species are reciprocally monophyletic (phylogenetic reconstructions) and are characterized by private alleles (allozymes; globin chains) and a variety of synapomorphic substitutional characters (cytochrome b and control region sequences). They diverged about 1.3 to 1.8 million years ago (cytochrome b and control region data).

Intraspecifically, the subspecific classification of both taxa has also been revised. Accordingly, *S. melanotheron* includes three subspecies: *S. m. heudelotii* (Dumeril, 1859) known from Senegal to Guinea, *S. m. leonensis* (Thys van den Audenaerde, 1971) known from Sierra Leone to western Liberia and *S. m. melanotheron* (Rüppell, 1852) found from Ivory Coast to Cameroon. *S. m. paludinosus* (Trewavas 1983) described near Dakar (Senegal) has been synonymized with *S. m. heudelotii*. Its sister species, *S. nigripinnis* originally described as *T. nigripinnis* and subsequently considered as *S. melanotheron nigripinnis* (see Trewavas 1983), is composed of the nominate subspecies, *S. n. nigripinnis* (Guichenot in Duméril, 1859) known from Gabon and a newly introduced subspecies, *S. n. dolloi*, originally described as *T. dolloi* (Boulenger, 1899) and previously synonymised with *S. m. nigripinnis* (see Trewavas 1983). It is presently known from the mouth of the Congo to the Lower Kouilou. The validity of all of these taxa is confirmed by molecular data sets. Detailed informations on this most recent revision of the black-chinned tilapia complex are available in Falk et al. (2000; in press).

T. guineensis (Bleeker, 1862) represents the third most important lagoon tilapia in West African coastal areas. It occurs sympatrically with *S. melanotheron* and *S. nigripinnis* and is also found in Angola. However, at present no subspecific

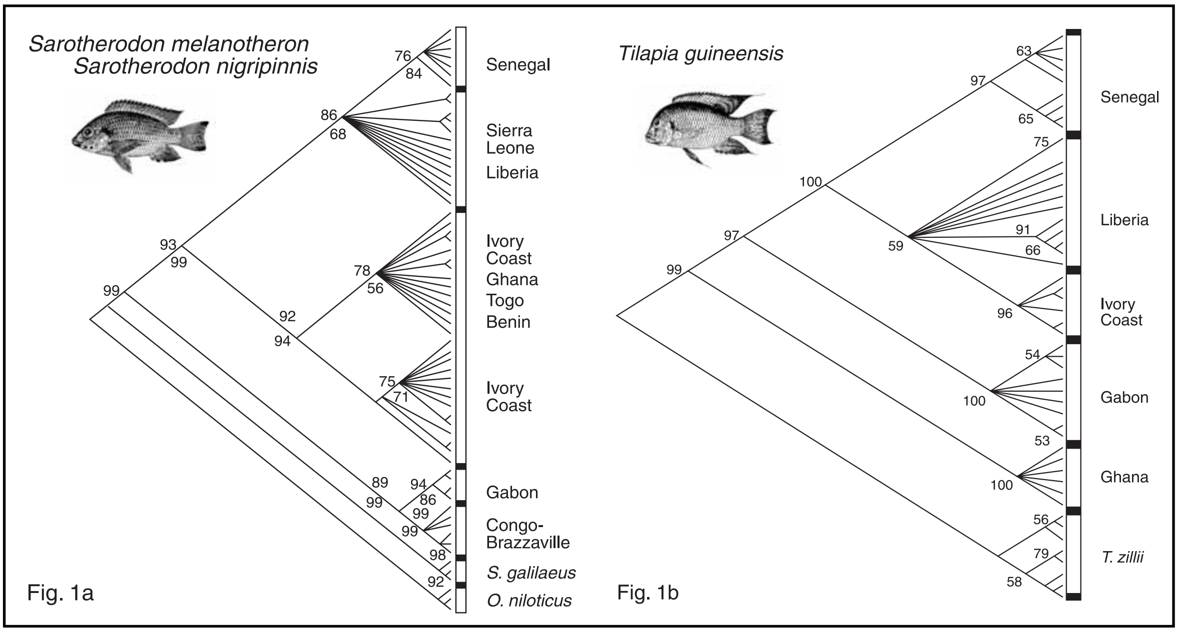

Figure 1. Phylogenetic relationships between mtDNA haplotypes of populations of *S. melanotheron*, *S. nigripinnis* and *T. guineensis* based on partial control region sequences (403-405 bp). Rooted neighbor joining trees. Numbers at the branches indicate percentage recovery of the particular node in 1000 NJ- (Fig. 1a,b) and 1000 MP-bootstrap replicates (Fig. 1a only, below branches). Equivalent topologies were found by maximum-likelihood analyses.

classification has been proposed for this species across its entire range. Results obtained so far make us doubt the validity of its presently known systematic status (Fig. 1b). Molecular analyses (cytochrome b, control region) clearly indicated substantial genetic divergences among geographically distinct populations. Four mtDNA lineages could be distinguished: (1) a Senegalese lineage, (2) a lineage covering the population of Liberia and Ivory Coast, (3) a Ghanaian lineage, and (4) a lineage from Gabon. Mean genetic distances between different lineages reached up to twice as much as those estimated for *S. melanotheron* and *S. nigripinnis*. Thus, comparable but also quite distinct phylogeographic patterns are present within these three lagoon tilapias. Further revisionary studies on *T. guineensis* are focusing on morphological variations and nuclear markers.

Biogeography and Microphylogeny

Biogeographic and microphylo-genetic studies on single taxa may reveal perspectives concerning the history and diversity of organisms within a complete geographic area. Such perspectives may also be of importance for the management and conservation of aquatic biodiversity. Here, we summarize our results on such studies for the three lagoon tilapias of West Africa.

Comparative microphylogenetic analyses (Fig. 1a) coincidentally indicate a basal position of *S. nigripinnis* within the black-chinned tilapia complex (allozymes, cyt-b, mtDNA control region). The Congo-Brazzaville and Gabon populations share some important potentially ancestral character states. It, therefore, appears reasonable to propose a center of origin for *S. melanotheron*/*S. nigripinnis* within the area of Gabon and Congo-Brazzaville. From this region the western range of West Africa (Senegal to Cameroon) may have been colonized in a single wave of invasion, followed by long-term isolation and allopatric diversification of both sisterspecies. Within a second migration period *S. melanotheron* populations may have subsequently colonized the areas from Senegal to Cameroon, most probably from areas close to Ivory Coast. From this region the western areas up to the mouth of the Senegal River were reached, whereas other populations independently colonized the eastern areas up to Cameroon (Fig. 2). This second and more recent center of origin for the populations of *S. melanotheron* is supported by the timing of diversification and also by significant nucleotide diversity differences among the populations examined.

Similar phylogeographic patterns are found in *T. guineensis*. Outgroup comparisons indicate a basal position of the mtDNA lineage from Gabon, a phylogenetically intermediate position of the Ghanaian lineage, and more derived positions for the lineages from Ivory Coast/Liberia and also for the Senegalese lineage (Fig. 1b).

Climatological events (extension and recession of water bodies) during the late Quaternary may largely explain differences and similarities in the faunal composition of West African areas, including the genetic similarities and divergences described here. We suggest that West African Pleistocene forest refuge zones (Maley 1991) may have strongly influenced the degree and level of genetic differentiation and thus the observed phylogeographic patterns within these lagoon tilapias (Fig. 2). During the late Quaternary tropical rain forest was confined to specific core areas during arid Pleistocene periods. These areas most probably also maintained aquatic habitats and thus may be considered to represent refuge zones for both African forest and aquatic organisms. Major important refuge zones and core areas (Maley 1991; Hamilton 1982) comprise eastern Congo, Angola, Cameroon/ Gabon, eastern Ivory Coast/western Ghana and Sierra Leone/Liberia. The spatial distribution of more ancient mtDNA lineages and the centers of intrapopulational genetic diversity clearly correspond to proposed lowland refuge zones and core areas of Central Africa. For *S. melanotheron* in particular refuge zones in Ivory Coast and Sierra Leone may have played an important role, whereas both subspecies of *S. nigripinnis* most probably evolved within refuge zones of Gabon and Angola. The Senegalese lineage of *S. melanotheron* (*S. m. heudelotii*) is considered a direct descendant of the Sierra Leone lineage.

A similar evolutionary scenario may be proposed for *T. guineensis*. However, Ivorian populations of this species most probably evolved within the Sierra Leone/Liberia core area and subsequently colonized the areas of Ivory Coast, as indicated by their close affinities to Liberian populations. Ghanaian populations, however, most probably evolved in the Ivorian/Ghanaian refuge zone, as indicated by their genetic distinctness. Up to which degree all of these areas have been influenced by the large Pleistocene East Congo core area presently remains unknown. For

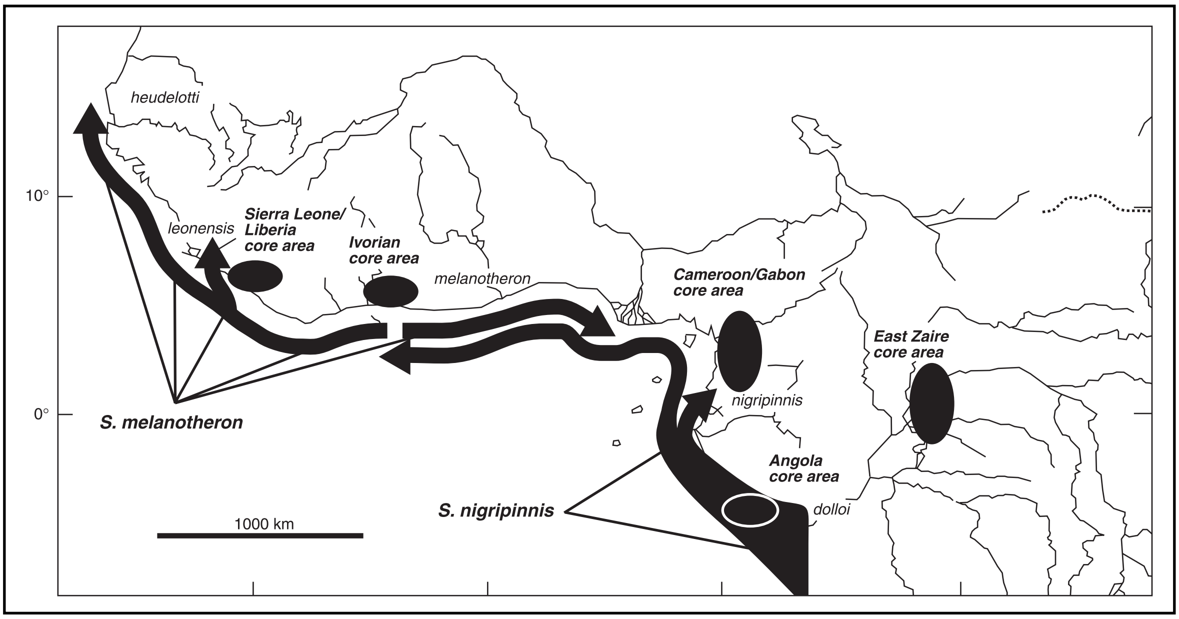

Figure 2. Pleistocene biogeographic scenario proposed for S. melanotheron/S. nigripinnis. Colonization events/expansions from the center of origin (Congo-Brazzaville/Gabon) are indicated by arrows. The distribution of core areas/refuge zones in equatorial Africa correspond to those proposed by Hamilton (1982) and Maley (1991), respectively. For T. guineensis a similar scenario is suggested (see text). The most recent systematic revision of S. melanotheron and S. nigripinnis is also indicated.

West African fishes in Pleistocene refuge zones thus may have been of substantial importance at both micro- as well as macro-evolutionary scales. For the development of management and conservation strategies the identification of such core areas and the characterization of their genetic diversity appears to be of special interest. Consequently, such studies may contribute to the development of more regional focused conservation plans and the identification of "high priority conservation areas".

Centers of Genetic Diversity

For the management of aquatic genetic resources, including restocking and selective breeding programs it may be of substantial importance to have an idea on the genetic diversity of populations in terms of a more geographical view. For example, in *S. melanotheron* highest nucleotide diversity estimates based on mtDNA control region data are found in populations from Ivory Coast (2.2%) and Sierra Leone/Liberia (1.6%). For populations from the mouth of the Senegal River these estimates drop to a π-value of 0.6%. Similar low π-values are found eastwards from Ivory Coast, in populations from Ghana, Togo and Benin (0.7%). These lower nucleotide diversities in populations near the limits of the distribution range of *S. melanotheron* suggest that they represent relatively recently derived populations. Allozyme data reveal comparable results. Higher mean and absolute heterozygosity and polymorphism rates are observed in areas close to Ivory Coast.

Preliminary results on *T. guineensis* indicate the presence of a major center of genetic diversity in Liberia (nucleotide diversity estimates based on mtDNA control region data). Moderate genetic diversity values are found in populations from Senegal, Ivory Coast and Ghana. Low genetic diversity values are characteristic of populations from Gabon. A high percentage of genetic diversity of these lagoon tilapias may thus be conserved by developing management and conservation strategies for such centers of genetic diversity only. In fact, centers of genetic diversity should at least be considered as "high priority areas" within management and conservation strategies. From this point of view, molecular biogeographical analyses are essential tools within conservation studies.

Conclusions

All three lagoon tilapias studied here represent important genetic resources in terms of genetic diversity. Their genetic architecture and the extent of genetic diversity of populations differ considerably and can largely be explained by climatic events during the late Quaternary. A continuation and extension of such studies and a better general knowledge of the biodiversity of West African fishes are fundamental for developing successful management and conservation strategies and to identify species and populations with potential for aquacultural purposes.

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Discussion

Mr. Changadeya: You mentioned that the populations from Senegal and Sierra Leone are close. Did you consider migration routes and gene flow between such populations? Do you suggest that the closeness of populations is due to common ancestry?

Dr. Falk: In fact, the populations from Senegal are considered direct descendants of the Sierra Leone lineage. We think it's the most recent split within the biogeographical senario suggested here. Migration routes and population expansions/recessions are following the refuge zone model. For what concerns gene flow, it could easily be estimated by the data according to Wright, but we did not focus on that particular equitation.

Mr. Changadeya: May I ask the speaker to give specific management and conservation approaches recommended by his study?

Dr. Falk: There are two main approaches for the management and conservation of *S. melanotheron, S. nigripinnis and T. guineensis:* a regional one and an approach focusing on specific unique populations (an organismic approach). We identified centers of genetic diversity across the entire range of all three lagoon tilapias and we would recommend considering these areas as "high priority areas" for what concerns the development of management and conservation strategies. In this sense, these areas are of real importance. The regional approach is thus more appropriate in my opinion. However, focusing on unique alleles other strategies may be considered.

Mr. Olaleye: Populations from the Nigerian and Cameroon coastline were not considered in the study. Are you sure the populations will not be different from those from Togo/Benin or the Gabon/Congo populations?

Dr. Falk: We expect that they represent *S. melanotheron* like those from Togo/Benin. Efforts to get samples from this region were, however, unsuccessful. There are indications that the species may be rare along the Nigerian and in particular the Cameroon coastline. At present, there are no data for this particular region.

Mr. Amakye: Are there any populations of interest (i.e. unique, threatened etc.) that must be conserved?

Dr. Falk: Yes, of course. There are populations that are completely unique and distinct from others. There are populations characterized by high genetic diversities and others with very low genetic diversities. There are also populations with very rare alleles. A high percentage of this diversity could be conserved focusing on the conservation of centers of genetic diversity only (Sierra Leone/Liberia and Ivory Coast). However, populations with unique alleles, for example, could also be of importance.

Dr. Abban: The idea of biodiversity is not to look for what is to be kept, but rather to know the range available for the species and how to keep them because the existence of one contributes to the existence of the other. Conserving one and leaving out others puts the whole biodiversity range at risk. What should be done to conserve biodiversity? The basic thing is to establish systems or programs to improve the knowledge of the biodiversity range of specific species, e.g. *S. melanotheron* from all areas where it is present.

Dr. Pullin: It might not be enough to concentrate efforts on the conservation of species in the areas of "high priority". This is because there may be rare alleles at the extremes of the species range. This simply means that you should have your conservation and use projects proceeding together and not isolated from each other.

Dr. Falk: Of course, the statements of Dr. Abban and Dr. Pullin are very correct. However, as it is not realistic to conserve everything in vivo, one has to choose what to conserve. In this sense, the identification of centers of diversity appears to be of special importance to me, perhaps also to you.

Maintenance and Utilization of Tilapia Genetic Resource in Egypt

M. Rezk
WorldFish Regional Center for Africa and West Asia,
PO Box 2416, Cairo, Egypt

The Nairobi declaration, February 2002, has been an important step toward setting the ground rules for responsible aquaculture/ fisheries production and, at the same time, realizing the rights of future generations to healthy and usable genetic resources. In the past, different countries have observed these recommendations up to one degree or another. In Egypt, several laws have dealt with issues related to aquatic genetic resources and biodiversity either directly or indirectly. These include the law of protected natural areas, the law of fishing and related trades and the law of environmental protection. In practice, there is a set of regulations and directives that govern introduction and exportation of live plants and animals in addition to related issues such as quarantine, registration of seed and commercialization of new varieties, testing and commercialization of genetically modified organisms (GMO's), and declaration of protected areas.

Alterations to aquatic genetic resources may have occurred in the past few decades. One of the major contributors to this may have been the construction of the High Dam at Aswan as a part of the countries freshwater conservation policy. With irrigation, water became available year-round and a different ecosystem has evolved in Lake Manzala and Lake Burullus, where freshwater species, including tilapia, dominated the lakes. Salinity gradients may allow the development of new patterns of environmental adaptations in the species living on both sides of the gradient. In Lake Qaroon, salinization is taking place because of the limited supply of drainage water and the concentration of salts due to evaporation. With an average salinity of 39 ppt, most freshwater species have disappeared from the lake except, maybe, at the agriculture drainage mouths.

Aquaculture activity is currently concentrated in the north of the country. The construction of the High Dam as well as other water conservation projects may have maintained so far a unidirectional flow of genes from south to north. This may have protected the southern gene pools from the possible impacts of escapees from aquaculture facilities in the north. Such impacts may, however, be possible when cage culture is allowed in the Nile or when fish farming intensifies and moves further south.

Utilization of tilapia genetic resources was initiated through comparative studies for important aquaculture traits which led to the identification of the best performing populations. A number of breeding studies have now been initiated to develop high performing lines under different aquaculture situations.

Discussion

Dr. Laleye: What is the socio-economic importance of tilapias in fisheries in Egypt?

Dr. Rezk: Tilapia is the most important species in many lakes in Egypt (in the Nile as well as in freshwater lakes).

Dr. Laleye: What are the problems of tilapia conservation in Egypt?

Dr. Rezk: The concern about tilapia conservation is about escapees from culture systems which is a potential problem.

Tilapia Genetic Resources: Their Conservation and Utilization in South Africa

Herman van der Bank
Department of Zoology, Rand Afrikaans University,
PO Box 524, Auckland Park, 2006, South Africa

Aquaculture of tilapia and other species in South Africa (SA) recently received a boost: 1) due to the favourable exchange rate for export, 2) because mad-cow disease caused a worldwide consumer resistance against red meat, and 3) because people are becoming more aware of the health benefits of fish in their diets.

Mass selection of rainbow trout and population genetic studies are done by post-graduate students at the University of Stellenbosch on abalone (*Haliotis midae*) in hatcheries, spiny rock lobster (*Jasus lalandii*), 12 *Oreochromis mossambicus* populations throughout southern Africa, *O. niloticus* and their hybrids. The results for the tilapia species showed altered allele frequencies for two groups of *O. mossambicus* sampled in 1999 and 2000, no significant correlation between average heterozygosity with average weight or length gain, and overlapping of allele sizes at individual levels between the two pure *Oreochromis* species (with those of the hybrids being intermediate) (Brink, pers. comm. 2002). The unlawful introduction of *O. niloticus*, Nile tilapia, in the Limpopo River system (Van der Waal and Bills 2000) remains a major concern in SA. It was also introduced in cage-culture in Namibia by nature conservation authorities. These fishes are bred at Hardap Dam and distributed throughout Namibia. If it escapes, then cross breeding with the endemic *O. andersonii* and *O. macrochir* would be possible. Nile tilapia have already hybridized with the endemic *O. mossambicus* (Moralee et al. 2000) in SA. It is still possible to identify some hybrids from morphological characteristics, but genetic confirmation by allozyme electrophoresis is recommended since the hybrids are fertile and cross breeding with either parent species will make identification even more difficult.

Catfish (*Clarias gariepinus*) farming is also becoming more attractive, e.g. one catfish farmer needs to produce 40-60 million fingerlings annually. The export of fresh and smoked fillets can earn 6.00 and 8.50 US dollars respectively (Le Roux, pers. comm. 2002). A 50 million-rand fish production plant was also set up in SA, where fingerlings are imported from Europe, grown to marketable size in SA and then exported. Polyculture of catfish and tilapia (e.g. *O. mossambicus* and *Tilapia rendalli*) is a main focus.

Acknowledgements – I thank the NRF and RAU for funding to attend the workshop.

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Discussion

Prof. Obiekezie: What I do not understand is why you have to import 50-60 million catfish fingerlings when South Africa had a well developed catfish aquaculture industry including hatchery production before?

Dr. van der Bank: People lost interest in culture. There are plans to produce cichlids and catfishes for distribution in the country.

Dr. Pullin: What do you have to say about issues of alien species crossing shared borders of countries which have different interests, desires and needs with respect to fishes?

Dr. van der Bank: There is a political aspect to this issue. For instance, guppies were proposed to eradicate mosquito larvae but were not introduced into the Limpopo river. Namibia introduced *O. niloticus* which is alien to their country and it is causing the disappearance of their native species.

Dr. Pullin: Neighboring countries sharing water systems should have similar interest. It is also important that awareness should be increased at all levels (from political leaders to the individuals) in different nations on the obligations accepted when such nations are signatories to the Convention on biodiversity.

Genetic Diversity of the Nile Tilapia *Oreochromis niloticus* (Teleostei, Cichlidae) from the Volta System in Ghana

Thomas M. Falk
Zoologisches Institut und Zoologisches Museum der Universität Hamburg, Martin Luther King Pl. 3, 20146 Hamburg, Germany

Eddie K. Abban
Water Research Institute, P.O. Box 38, Accra, Ghana

The Nile tilapia *Oreochromis niloticus* (L. 1758) is endemic to Africa but has been introduced into many different areas of the world for aquacultural purposes. Today, it is one of the most cultured freshwater species worldwide, in particular the subspecies *O. niloticus niloticus* (Garibaldi 1996).

In Ghana, the Volta system, including the Volta river, the Volta lake, and their tributaries, like rivers Oti, Pru, White Volta, Black Volta and Asukawkaw, drains more than two thirds of the country (Dankwa et al. 1999). Here, the Nile tilapia and the Mango tilapia, *Sarotherodon galilaeus* (L. 1758), constitute an important part of commercial fish stocks (Ofori-Danson 2000) and commercial culture activities focusing on the Nile tilapia have recently been started at lake sites. However, comparative molecular genetic studies on the population of the Nile tilapia from the Volta system including the lake are virtually missing.

In this contribution, we present a first attempt to study the genetic diversity of the Nile tilapia population from the Volta lake and tributaries of the Volta system. Materials from three lake sites (Kpandu, Kope and Yeji) and four riverine sites (Nawuni, Botanga, Pru and Mepe) were examined. We analyzed the most variable element of the mitochondrial genome, the first hypervariable region of the control region (405 bp), and comparatively studied nuclear variations (RAPDs: randomly amplified polymorphic DNA). Overall, 127 specimens were examined.

Results so far clearly indicate an essential genetic structure within this population. As indicated in Fig. 1, two major mtDNA lineages are present, covering a total of 12 different mtDNA haplotypes. The most common haplotypes (H1-4) of both major mtDNA lineages are found across all sampling sites. However, all other haplotypes (H5-12) show a spatially distinct distribution (Fig. 1). For example, haplotypes 5,6,7 and 8 are only found in Kope and/or Kpandu, whereas haplotypes 11 and 12 are only found in the Pru. The majority of private (area specific) haplotypes are thus found at Kpandu/Kope and within the Yeji and Pru areas. Within the northern sampling localities, Nawuni/Botanga, and below the Akosombo dam at Mepe, only the most common haplotypes (H1-4) are present.

Genetic diversity comparisons among different localities reveal similar results. Highest nucleotide diversity values based on control region data are found within the more central areas of the system: Kpandu/Kope and Yeji/Pru. Together

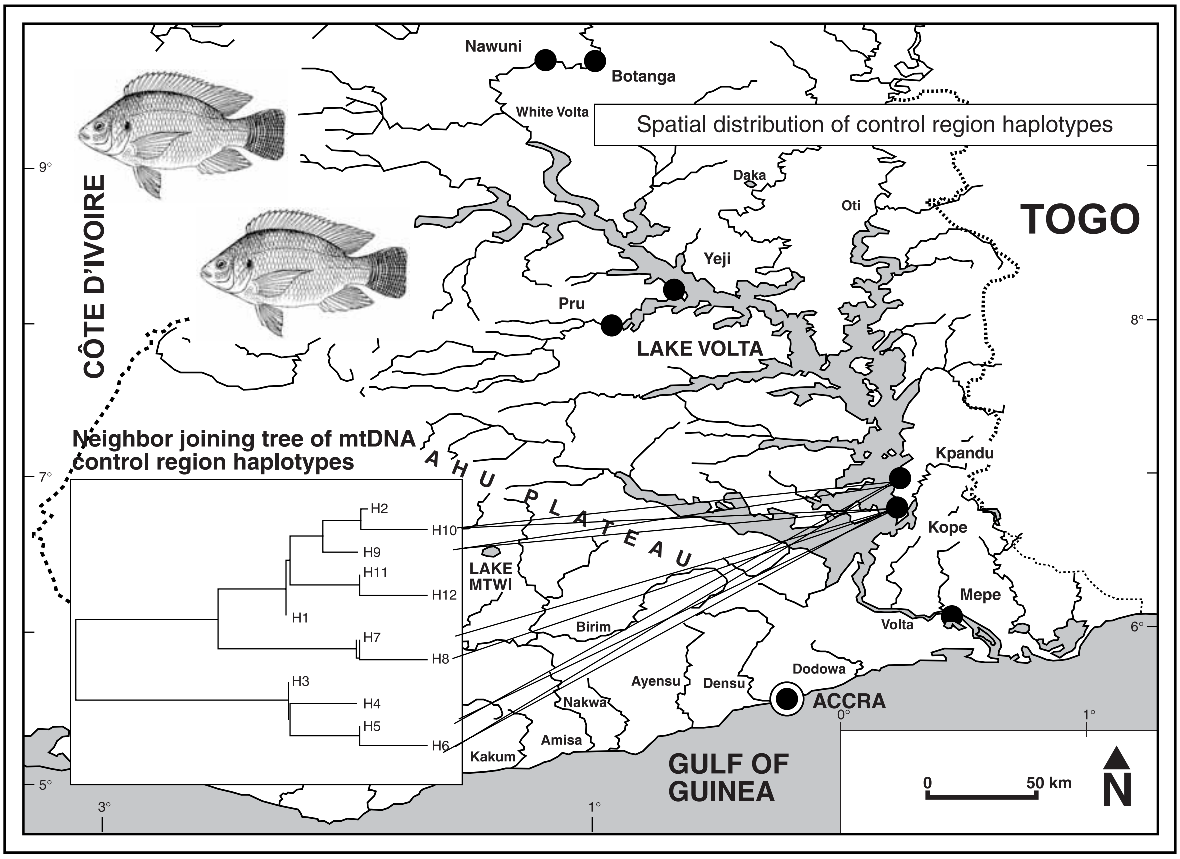

Figure 1. Spatial distribution and genetic relationships of mtDNA control region haplotypes (H1-12) of the Nile tilapia from the Volta system. H1-4: most common haplotypes present in all sampling sites. H5-12: haplotypes confined to specific areas.

these four areas contribute more than 70% of the genetic diversity of the material examined. In the northern area (Botanga/Nawuni) and below the Akosombo dam (Mepe) quite low diversity values are found.

Preliminary results based on RAPD analyses coincidentally confirmed a genetic diversity cline from southern (Kope/Kpandu) to northern (Nawuni/Botanga) areas of the system. Highest nucleotide diversities estimated by RAPD analyses were again found at Kpandu/Kope followed by Yeji/Pru. Overall, nine different RAPD primers were used.

In addition, we also studied an introduced Nile tilapia population from the Densu reservoir and a farmed stock obtained from the Water Research Institute in Accra. Both samples were characterized by quite low genetic diversities (control region data; RAPDs).

In conclusion, the Nile tilapia of the Volta system represents an important genetic resource in terms of genetic diversity. So far, molecular diversity peaks are found within the southern areas of the system (Kpandu/Kope and Yeji/Pru). A better knowledge of this diversity and comparative studies, for example, on the Mango tilapia may greatly improve management and conservation strategies applicable to this important fishing area.

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Discussion

Mr. Amakye: What could be responsible for the apparent separate populations on the Pru/Yeji area and the southern parts of Lake Volta? There is no barrier between these two areas; how do you explain the distinct populations?

Dr. Falk: There is a small missunderstanding. These populations are not completely distinct. What we found is a genetic structuration within the Nile tilapia population. The areas you mentioned differ in the extent of genetic diversity and the distribution of different haplotypes. Lowest genetic diversities are found in the northern areas of the system. At present, this genetic diversity cline may probably be best explained by quite low numbers of migrants among different localities, in the sense of restricted gene flow. However, both major mtDNA lineages found here most probably evolved before Lake Volta was created and entered the Lake from, for example, the White and the Black Volta, as indicated by the timing of diversification of both lineages. Again, we found a genetic structure within the Nile tilapia population, but we did not find genetically completely isolated units.

Evaluation of Early Life Culture Performance of Ghanian Populations of *Sarotherodon melanotheron* (Teleostei, Cichlidae)

E. K. Abban
Water Research Institute, Accra, Ghana

T.M. Falk and S.K. Agyakwah
Zoologisches Institut und Zoologisches Museum der Universität Hamburg,
Martin Luther King Pl. 3, 20146 Hamburg, Germany

The Black-chinned Tilapia, *Sarotherodon melanotheron* occurs naturally and abundantly in the coastal waters of West Africa (Trewavas 1983; Trewavas and Teugels 1991). In Ghana, it is the most abundant fish (65-98%) in all of the 60 lagoons and estuaries along the 550 km coastline (Falk et al. 1999; Abban et al. 2000). *S. melanotheron* which may be the only remaining fish in some relatively smaller lagoons along Ghana's coast is threatened by pollution, siltation of lagoons, over-fishing, destructive fishing methods, habitat degradation and destruction (Abban et al. 2000). It is, however, identified as the most promising species for increasing fisheries production of lagoons in West Africa and Ghana in particular.

Since 2000, populations of *S. melanotheron* in Ghana have been evaluated for their reproductive and growth performance to identify better brood fish sources to increase production of fish in their natural and cultured environments.

This report emphasizes the relative early life culture performance of four populations of *S. melanotheron* from Aminsa estuary, Densu estuary/reservoir, Sakumo lagoon and Volta reservoir at Akosombo. The evaluation focused on spawning frequency, spawn size, survival, and growth (Daily Growth Rate / Specific Growth Rate) in three nursery facilities.

There were no significant differences in the spawning interval (or frequency) among the populations studied. However, continuous spawning was observed, indicative of tilapias in captivity (Lazard and Legendre 1996) and in stress (e.g. excessive fishing pressure and pollution).

The populations from Densu and Volta (Akosombo) seem to have similar capacities for fry production per individual spawn, compared to the populations from Aminsa and Sakumo. Incidentally, both Densu and Volta (Akosombo) are less saline compared to Aminsa and Sakumo. Salinity may have an influence on *S. melanotheron's* reproductive capacity.

Ponds seem to have provided conducive environments (e.g. availability of natural fish food organisms), which supported life of population fry, compared to environment of the concrete tank. There was evidence of different growth rates of populations in different environments (hapa, tank and pond). However, within each culture environment growth rates were not statistically different among populations (P = 0.05).

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Discussion

Dr. Pullin: Could you comment on how the data were treated statistically?

Mr. Agyakwa: ANOVA was the treatment used; however, the work did not have enough replicates.

Mr. Amakye: Level of salinity seems to have had an impact on growth in your study. What levels of salinity affect growth of *S. melanotheron*?

Mr. Agyakwa: We learned from literature that salinity probably affects performance. Observations made from the study indicated that salinity probably affects performance; however, we have not pursued this.

Mr. Kwarfo-Apegyah: With respect to food supply in the three systems, was there any supplementary feeding?

Mr. Agyakwa: The same food source was used for the three systems. With respect to hapas, space limitation affected food quantity and thus growth.

Mr. Kwarfo-Apegyah: Growth rates of fish larvae cultured in pond were higher compared to that in tanks and hapas. Why was this so, since hapas were erected in the same ponds?

Mr. Agyakwa: Both tanks and hapas had limited space for free mobility. Moreover, fry feed introduced into hapas easily escaped through pores of the net hence limiting feed availability. Compared to tanks, ponds additionally had the capacity for biogenesis of fish food organisms thus increasing food availability to fry, hence we see higher growth rate in ponds.

Dr. Pullin: It may be important to generate growth curves for this study which could be compared with growth curves from other studies in literature.

Evaluation of Culture Performance of Ecotype Collections of Nile Tilapia (*Oreochromis niloticus*) from the Volta System as the Basis for Fish Breeding and Selection Program in Ghana

Felix K. Attipoe and Eddie K. Abban

CSIR - Water Research Institute, P.O. Box 38, Accra, Ghana

The objective of this study was to compare the relative growth performance of three ecotype collections of Nile tilapia, (*Oreochromis niloticus*) [Guinea Savanna ecotype – NA, Transitional ecotype – YE, and Semi-deciduous forest ecotype – KP] from the Volta system in Ghana. Early growth of *O. niloticus* fry of the three ecotypes were evaluated in two experiments using: (I) separate rearing 200 m^2 earthen ponds at a stocking density of 30 000 fry ha^{-1}, and (II) using a communal concept while keeping the ecotypes separate in 1 m^2 hapas at a stocking density of 67 m^{-2}. All hapas were installed in a 0.2 ha earthen pond. Experiments (I) and (II) lasted 55 and 42 days, respectively. A third experiment evaluated the performance in 50 m^2 earthen ponds at 2

fish/m^{-2} using three diets F1, F2, F3, and F0 (no feeding). Crude protein levels of the diets were 15%, 9% and 15%, respectively. Experiment (III) lasted 150 days. The average fecundity (AF) which was calculated as the number of seed produced divided by the number of female spawners in a breeding cycle was determined for the three-ecotypes in a six-month breeding cycle.

Relative AF were 253, 176, and 145 for YE, KP, and NA ecotypes, respectively. The overall growth results were: (a) NA grew fastest and recorded the highest mean body weight gain across all treatments for both males and females. However, differences between NA and KP and YE were not significant; (b) There was a differential growth performance of males and females of all ecotypes. Females weighed between 72%-83% the weight of males across all treatments; (c) Least square means computed for final body weight within feed treatments indicated a significant difference ($P < 0.05$) between the growth performance of the three ecotypes at fingerlings to adult stage. KP and NA showed insignificant differences among replicates while YE was significantly lower for final body weight; (d) Relative overall ranking in terms of mean gain in body weight was NA > KP > YE.

Based on growth performance of the three *O. niloticus* ecotypes, NA and KP could be recommended as the most promising ecotypes to use as base population for a breeding and selection program in Ghana; however, in order to increase the variability among the genes and improve other traits such as survival and fecundity, it would be necessary to conduct a diallel cross experiment which would include all three ecotypes. Results from the diallel cross experiment could increase the additive and non–additive genetic variance for selection using a synthetic base population formed from the best performing cross combinations.

Discussion

Mr. Boa-Amponsem: You have shown that one line (Yeji/YE) has the best fecundity but lower growth performance compared with the other (Nawuni/NA). I am not sure whether in fish there is a negative genetic correlation between growth and fecundity. Another strategy other than the synthetic line formation would be to establish the two lines of (NA) as separate male and female lines for growth and other for fecundity. The final (terminal) cross would then possess both traits, namely high growth rate and high fecundity. I am an animal geneticist and this is what we do. I want to put it across to see if it is applicable in fishes.

Dr. Rezk: In one of our experiments, we noticed that there were differences in weights between the sexes. Have you observed a similar trend in your study?

Mr. Attipoe: Yes.

First Results on the Aquaculture Potential of a Landlocked Population of the Black-chinned Tilapia, *Sarotherodon melanotheron*, in a Man-made Lake, Ayame (Côte d' Ivoire)

N.I. Ouattara[1] and J.C. Philippart
Université de Liège, Laboratoire de Démographie des Poissons et d'Aquaculture 4500 Tihange, Belgium

G.G. Teugels
Laboratoire d'Ichtyologie, Musée Royal de l'Afrique Centrale B-3080 Tervuren and KULeuven, Laboratory of Comparative Anatomy and Biodiversity, B-3000 Leuven, Belgium

V.N. Douba
[1] Université de Cocody, UFR-Biosciences, Laboratoire d'Hydrobiologie, Abidjan, Côte d'Ivoire

In West African coastal waters, over 40 fish families have been reported by Lévêque et al. (1992). One of the major fish found in this zone is the Black-chinned Tilapia *Sarotherodon melanotheron* (Teugels and Falk 2000). This species is considered a brackish water tilapia, generally found in estuaries and lagoons and occasionally in the mouth and lower course of coastal basins from Senegal to Congo (Trewavas and Teugels 1991). *S. melanotheron* is an important fish in the commercial and subsistence fisheries of many West African lagoons (Ekau and Blay 2000).

Lake Ayame (Côte d'Ivoire) is a man-made lake in which a population of *S. melanotheron* has been landlocked following the construction of the dam in 1959. Fishery statistics show that this species alone represents 51% of commercial fisheries, which, in 1996, exceeded 1000 t (Gourène et al. 1999).

The aquaculture potential of this species has already been studied in the Ebrie Lagoon (Côte d'Ivoire) by Legendre (1986), Legendre et al. (1989) and Gilles et al. (1998) and in ponds in Nigeria by Eyeson (1983). Growth rates obtained are not impressive (between 0.32 and 0.50 $g.d^{-1}$) and do not favour commercial culture.

In view of the success of *S. melanotheron* in Lake Ayame, a four-year project between the University of Cocody (Côte d'Ivoire) and the Musée Royal de l'Afrique Centrale (Belgium) was started in 1999 to test the zootechnical performances of the landlocked population of this species in Lake Ayame. In this paper, we summarize main results recorded so far during this study.

- *Growth comparison between the landlocked and a natural population of S. melanotheron*
  In this trial, fishes were reared from 9 to 39 g (first experiment) in 140 days at the stocking density of 100 fish/m^3 and from 39 to 147g (second experiment) in 350 days at 50 fish/m^3. Survival rate (89.33% for the first experiment and 97.33% for the second), mean daily weight gain (0.22 $g.d^{-1}$ first experiment and 0.26 $g.d^{-1}$ second experiment) and food conversion ratio (7.49 first experiment and 11.41 second experiment) were better for the landlocked population compared to those of the natural population (85.00 and 92.00%, 0.18 and 0.22 $g.d^{-1}$ and 9.54 and 12.81, respectively) reared in freshwater conditions in Lake Ayame. Condition factors recorded during these experiments for landlocked and natural populations were 3.5816 and 3.5879, respectively.

- *Comparative study of the effect of stocking density on growth performance of the landlocked population*
  The influence of four stocking densities (20, 50, 100 and 150 fish/m^3) was tested for 336 days. The results showed that survival rate, mean daily weight gain and food conversion ratio were good at 20 fish/m^3 (100%, 0.32 $g.d^{-1}$ and 11.24, respectively). Except for the survival rate (which was 83.00% at 100 fish/m^3), the others parameters were poor for 150 fish/m^3 (0.27 $g.d^{-1}$ and 12.29, respectively). Results of this study correspond with observations reported in several other studies (Dambo and Rana 1992; Liu and Chang 1992; Suresh and Lin 1992) but are opposite to records obtained by Legendre et al. (1989).

- *Determination of the feeding rate of the landlocked population*
  For this trial, 8 fish groups (weight between 12 and 131 g) were reared for 90 days in floating cages. Fishes were fed *ad libitum* using demand feeders (capacity 2 kg). Food consumption was noted every day. Results showed that the daily food intake of each fish group increased with fish weight. Relation between these parameters (food consumption and body weight) can be represented by the equation: $F.C. = 0.7166.W^{0.4408}$; r = 0.7852; n = 24 with F.C.: food consumption (g) and W: weight (g). Survival rate, mean daily weight gain and food conversion ratio recorded in this trial were relatively high at 128.77 g (100%), 44.33 g (0.72 $g.d^{-1}$) and 12.65 g (12.77) and low at 12.65 g (76.67%), 12.65 g (0.50 g.d-1) and 91.15 g (6.03). Mean values observed for all the groups were 95.75% (survival rate), 0.63 $g.d^{-1}$ (mean daily weight gain) and 8.94 (food conversion ratio). These parameters are better than those noted in the first trial of this study and in studies undertaken by Legendre (1986) and Legendre et al. (1989).

- *Effect of demand feeder on growth performances of the landlocked population*
  For this trial, all male populations (weight between 18 and 72 g) were reared for 90 days in floating cages. One fish group was fed using the demand feeder while the second was fed by hand. The results recorded in this study showed that survival rate was the same (98%) for the two groups. Mean daily weight gain and food conversion ratio were 0.59 $g.d^{-1}$ and 7.06 for the first group and 0.57 $g.d^{-1}$ and 6.99 for the second. Contrary to what could be expected according to the food intake habit of *Sarotherodon melanotheron* (see Pauly 1976) and observations made by Balarin and

Haller (1982) with demand feeders, these results showed that growth perfomances of *S. melanotheron* fed with demand feeder or by hand are not significantly different.

- *Comparison of the growth of the landlocked population in raceways, ponds and cages*
  This test was conducted during 90 days with all male populations sorted out at 11 g and grown to 54 g. Fish were fed *ad libitum* using demand feeders. Growth parameters recorded in each environment showed that survival rate was high (92.50%) in cages and low (72.79%) in ponds. The best mean daily weight gain and food conversion ratio were observed for fishes reared in ponds (0.47 $g.d^{-1}$ and 6.13, respectively) and low values were noted in raceways (0.19 $g.d^{-1}$ and 17.64, respectively). Observations made in this study showed best growth performances for fishes reared in ponds. These results are similar to records made by Melard (1986) with *Oreochromis niloticus*.

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The Utility of Complete Cytochrome b Sequences for Phylogenetic Studies on African Tilapiines (Teleostei, Cichlidae)

T. M. Falk

Zoologisches Institut und Zoologisches Museum der Universität Hamburg, Martin Luther King Pl. 3, 20146 Hamburg, Germany

Abstract

Phylogenetic hypotheses concerning generic interrelationships of tilapiine fishes are mainly based on morphological and ethological characteristics and biogeographical patterns. The present study examines the utility of complete cytochrome *b* (cyt-*b*) sequences to resolve basal relationships among the three main genera of African tilapiines and to address basic systematic issues. Phylogenetic analyses provide support for the monophyly of the mouth-brooding lineage including the genera *Sarotherodon* and *Oreochromis*, and also indicate a single origin of mouth-brooding taxa from substrate spawning species of the genus *Tilapia sensu stricto*. Both lineages, e.g. *Tilapia s.s.* and *Sarotherodon/Oreochromis*, diverged about 8 to 12 million years ago. However, no support was found for the validity of the mouth-brooding genera, e.g. *Oreochromis* and *Sarotherodon*. Moreover, cyt-*b* sequences were found to be systematically highly informative.

Introduction

The systematics and phylogeny of tilapiine fishes (Regan 1920; 1922) has attracted interest over the years. Thys van den Audenaerde (1970, 1971,1978, 1980) created a single genus, *Tilapia sensu lato*, covering a number of subgenera. Trewavas, however, divided the genus *Tilapia sensu lato* into three major genera: (I) the genus *Tilapia sensu stricto,* including substrate-spawning species; (II) the genus *Sarotherodon*, including biparental or paternal mouth-brooding species; and (III) the genus *Oreochromis*, including maternal mouth-brooders only (Trewavas 1966, 1973, 1980, 1981, 1982a,b, 1983). The separation of the mouth-brooding taxa into two genera was explained as follows (Trewavas 1983): *"This expresses the view that, although Sarotherodon and Oreochromis probably arose from substrate-brooding Tilapia, they may have come from different species. It follows the lead given by the studies of reproductive behavior and development by H. M. Peters and his pupils in Tübingen* (Peters and Berns 1978a, 1982)*, and is supported by geographical and anatomical features, which, though supplying few trenchant differences, have cumulative value".*

Ten additional genera were included in the tilapiines by Trewavas (1983): *Danakilia*, *Iranocichla*, *Konia*, *Myaka*, *Tristramella*, *Pelmatochromis*, *Pungu*, *Stomatepia*, *Steatocranus* and *Pterochromis*. However, according to Stiassny's (1991) definition of tilapiines the genera *Pelmatochromis*, *Steatocranus* and *Pterochromis* are excluded. Moreover, Stiassny (1991) also seriously questioned the tilapiine-haplochromine dichotomy of African cichlids (see also Trewavas 1983; Greenwood 1978, 1986, 1987; Kullander 1998).

In order to analyze basic phylogenetic relationships among tilapiines and to test alternative phylogenetic hypotheses concerning a multiple or single origin of mouth-brooders from substrate-spawning tilapiines, several genetic studies focusing on allozyme variations have been conducted (Kornfield et al. 1979; McAndrew and Majumdar 1984; Abban 1988;

* Corresponding author. Fax: +49 40 42838 3937
Email address: thomas.falk@uni-hamburg.de (T.M. Falk).

Seyoum 1989; Sodsuk and McAndrew 1991; Pouyaud 1994; van der Bank 1994; Pouyaud and Agnèse 1995; Sodsuk 1993; Sodsuk et al. 1995; B-Rao and Majumdar 1998; Feresu-Shonhiwa and Howard 1998). Coincidentally, these studies often support the existence of the three main genera proposed by Trewavas (1983) and, moreover, also indicated a single origin of mouth-brooding species from the genus *Tilapia s.s.* (Pouyaud and Agnèse 1995).

Molecular studies on phylogenetic relationships among the three major genera of tilapiine fishes as defined by Trewavas (1983) are rare (Sodsuk 1993; Franck et al. 1994; Schliewen et al. 1994; Nagl et al. 2001; Klett and Meyer 2002). Franck et al. (1994) demonstrated the use of SATA satellite DNA sequences. Cladistic and phenetic analyses of derived consensus sequences revealed two distinct clades: (I) *Tilapia s.s.* and, (II) *Sarotherodon* and *Oreochromis*. Moreover, based on partial phylogenies of tilapiines (Sodsuk 1993; Schliewen et al. 1994) results of Goodwin et al. (1998) suggested that mouthbrooding evolved only once in tilapiines, supporting Trewavas (1980) primary hypothesis.

Nagl et al. (2001) analyzed the most variable element of the mitochondrial genome of 42 tilapiine taxa, e.g. the first hypervariable region of the control region, and failed to resolve any phylogenetic relationships between putative monophyletic groupings. However, most recent studies on mitochondrial ND2 gene sequences of 39 tilapiine taxa (Klett and Meyer 2002) questioned the monophyly of the tilapiine assemblage and also indicated several independent origins of mouthbrooding behaviors in cichlids.

In this paper, we present a first attempt to study the utility of complete cytochrome *b* sequences for inferring phylogenetic relationships among the three major genera of tilapiine fishes as defined by Trewavas (1983) and to analyze correspondence with morphological characteristics and published genetic data sets.

Materials and Methods

Samples from Senegal, Liberia, Ivory Coast, Ghana, Gabon, Congo-Brazzaville, Egypt, Kenia and Mozambique were collected from January 1996 to March 2002. The geographic origin of the species and the number of specimens examined for each of them are listed in Table 1. Cytochrome *b* sequences of *Tylochromis polylepis* were obtained from GenBank.

Substitutional variations in sequences of the cytochrome *b* gene (cyt-*b*) were analyzed by PCR and direct automated sequencing of the amplified products. Total genomic DNA was isolated from frozen or ethanol preserved muscle tissue (100 mg) by phenol/chloroform extraction (Hillis et al. 1990). Complete cyt-*b* genes were amplified using primers L14724 and H15915 as listed by Irwin et al. (1991). PCR reactions were performed in 50µl reaction mixtures containing 1x reaction buffer (Proof*Sprinter* kit, Hybaid), 3.5 mM $MgCl_2$, 1.2 µM of each primer, about 40-90 ng total DNA, 0.4 mM of each dNTP (dNTP-Mix, Hybaid) and 1.5 units Tag/Pwo polymerase mixture (Proof*Sprinter*, Hybaid). The thermal profile was: 1. 94°C/2 min (1 cycle); 2. 94°C/20 sec; 56°C/90 sec; 72°C/120 sec (35 cycles); 3. 72°C/15 min (1 cycle). Amplified PCR products were purified by electrophoresis on 1.5% QualexGold agarose gels (Hybaid) and recovered using GFX PCR gel extraction kits (Amersham Pharmacia Biotech Inc). The purified double-stranded mtDNA products were used directly in dideoxy-termination sequencing reactions using the BigDye Terminator Cycle Sequencing Mix (Applied Biosystems). The light strands were sequenced in two steps using primers L14724 and a newly developed one L556-575 (5-CCCTTCATCATTGCAGCTGC-3), specific

Table 1. Geographic origin and abbreviations of the species examined and the number of specimens studied for each taxon. (Nn: unknown origin; *N*: number of specimen)

Species	Country (origin)	*N*
1. *O. niloticus*, Onil	Ghana, Gh	4
2. *O. niloticus*, Onil	Kenya, Ke	3
3. *O. niloticus*, Onil	Egypt, Eg	3
4. *O. aureus*, Oaur	Egypt, Eg	3
5. *O. andersonii*, Oand	Nn	3
6. *O. mossambicus*, Omos	Mozambique, Mo	3
7. *O. mossambicus*, Omos	Nn	1
8. *S. galilaeus*, Sgal	Egypt, Eg	4
9. *S. galilaeus*, Sgal	Ghana, Gh	4
10. *S. melanotheron*, Smel	Senegal, Se	3
11. *S. nigripinnis*, Snig	Congo, Co	4
12. *T. sparmanii*, Tspa	Southern Africa, Sa	4
13. *T. cabrae*, Tcab	Gabon, Ga	2
14. *T. zillii*, Tzil	Ivory Coast, Iv	4
15. *T. rendalli*, Tren	Nn	3
16. *T. guineensis*, Tgui	Ivory Coast, Iv	4
17. *T. guineensis*, Tgui	Liberia, Li	4
18. *T. busumana*, Tbus	Ghana, Gh	4
19. *T. discolor*, Tdis	Ghana, Gh	4

for nucleotide positions 556-575 of the cyt-*b* gene of tilapias.

Cycle sequencing reactions were performed in 20 µl reaction volumes containing 3 µl BigDye, 5µl 2.5x sequencing buffer (Applied Biosystems), 10 µl of the amplified products (200-350 ng) and 2 µl primer (1 µM). The thermal profile was: 96°C/ 30 sec; 55°C/15 sec; 60°C/4 min (30 cycles). After removal of unincorporated dye terminators (DyeEx, Qiagen) sequencing reactions were denatured and the samples were run on an ABI Prism 377 automated sequencer (Applied Biosystems). Complete cyt-*b* sequences (N=26) were subsequently deposited in GenBank.

Sequences were further processed and aligned (ClustalW) using BioEdit version 5.0.9 (Hall 1999). Alignments were subsequently optimized by eye. Nucleotide compositions and genetic distance values were determined with MEGA2 version 2.1 (Kumar et al. 2001) and PAUP 4.0b.8a (Swofford 2000). Substitutional saturation analyses were carried out using DAMBE version 4.0.75 (Xia and Xie 2001). Unique mtDNA haplotypes were analyzed by MEGA2 version 2.1 (Kumar et al. 2001) and PAUP 4.0b.8a (Swofford 2000). Phylogenetic analyses of sequence data were performed using Kimura's genetic distance estimates (Kimura 1980), corrected distances according to Tamura and Nei (1993), or uncorrected p-distances and the minimum-evolution (ME) algorithm. Bootstrapping always comprised 1 000 replicates. Maximum-parsimony (MP) trees were generated by heuristic search using PAUP 4.0b.8a (Swofford 2000). Character state-optimization was carried out by accelerated transformation and gaps were treated as transversions or completely deleted. Tree topologies were tested by bootstrapping (1 000 replicated). Maximum-likelihood (ML) analyses PAUP 4.0b.8a (Swofford 2000) were conducted choosing the HKY85 model with gamma distribution rates. Optimal transition/transversion rate ratios, base frequencies and among site heterogeneities were estimated. These model parameters were used for ML analyses (heuristic search). Bootstrapping comprised 500 replicates.

Results and Discussion

Variations in cytochrome *b* (cyt-*b*) sequences were studied from a total of 64 specimens covering samples from 19 different tilapiine populations. Comparative analyses with published cyt-*b* sequences of *Oreochromis mossambicus* (Cantatore et al. 1994) were conducted in order to check the identity of the obtained sequences and to derive codon positions.

The sequenced mtDNA region contained 1140 nucleotides that code for 380 amino acids of the complete cyt-*b* gene. An overall average of 7 amino acid differences was found among all specimens examined (min.: 0; max.: 19). The majority of variations occurred at the third codon positions, including moderate transition/transversion ratios in pair-wise sequence comparisons. Despite sequence variability among different haplotypes no significant differences were noted in base compositions across sequences or taxa (chi-square tests of homogeneity of base frequencies). Substitutions were identified at 369 of the 1 140 sites (32%), of which 343 (93%) were silent mutations.

Overall, 26 different mtDNA haplotypes were detected among the 64 individual samples sequenced. Corrected Kimura's genetic distances (Kimura 1980) between different haplotypes ranged between 0.003 and 0.190. Scatter plots of pair-wise genetic distances versus the number of transitions and transversions for all haplotypes suggested that substitutions accumulate linearly with an increase of genetic distances (Fig. 1). However, a significant decrease in transitions was noted above a genetic distance of about 0.145. The 336 of the 369 polymorphic sites appeared to be parsimony-informative.

The first step of the phylogenetic analyses only considered transversional substitutions. Cyt-*b* sequences of *Tylochromis polylepis* were used for outgroup comparisons. As indicated in Figure 2,

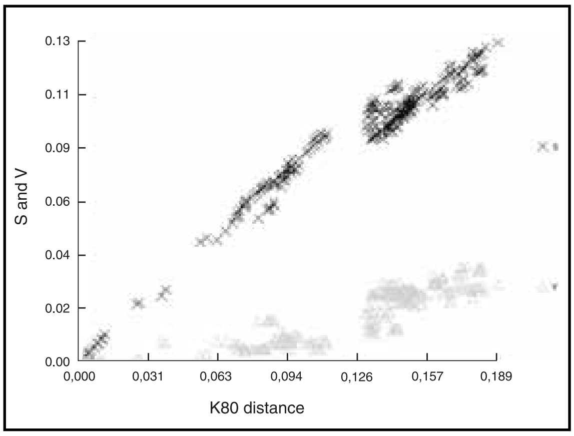

Figure 1. Plot of the number of transitions (s) and transversions (v) in pair-wise sequence comparison against genetic distance values for 26 cytochrome *b* haplotypes of different tilapia species.

the first and second positioned transversions separate most of the species of the genus *Tilapia s.s.* from all mouth-brooding taxa (*Oreochromis* spp., *Sarotherodon* spp.). However, this does not concern cyt-*b* haplotypes of *T. sparrmanii* and *T. cabrae*; these substrate-spawning taxa are clustered with mouth-brooding species. Moreover, all the species of the genus *Tilapia sensu lato* are clearly separated from *Tylochromis polylepis*. Bootstrap values reached 85%.

In a second step, the first, second and third positioned transversions were analysed. Figure 3 presents such a rooted minimum-evolution phylogeny. The consensus tree displays a topology with some similarities to that obtained previously. The species examined are clustered into three major clades highly supported by bootstrapping: (1) *T. discolor*; (2) *T. guineenis*, *T. busumana*, *T. zillii*, *T. rendalli*; (3) *T. cabrae*, *T. sparrmanii*; *O. niloticus*, *S. galilaeus*, *O. aureus*; *S. melanotheron*, *S. nigripinnis*, *O. andersonii* and *O. mosambicus*. Moreover, *Oreochromis* and *Sarotherodon* species are also clearly separated from *T. cabrae* and *T. sparrmanii* (bootstrap value: 91%). Without any exception all taxa of the genus *Tilapia s.s.* are found in basal positions of the rooted mitochondrial phylogeny. *T. cabrae* and *T. sparrmanii* are found in close sistergroup positions of the *Oreochromis* and *Sarotherodon* species examined. Further supported clades within the mouth-brooding taxa and the genus *Tilapia s.s.* are indicated in Figure 3. Similar phylogenies were also found by maximum-parsimony and maximum-likelihood analyses.

Phylogenetic reconstructions based on the first, second and third positioned tranversions and transitions revealed similar topologies (Fig. 4). However, the positions of *T. cabrae* and the species of group 2 (*T. guineenis*, *T. busumana*, *T. zillii*, *T. rendalli*) could not be determined with confidence; most probably a result of transitional sequence saturation effects.

As indicated above, the third positioned transversions seem to carry most of the phylogenetic signals required to resolve basal nodes and also to support terminal nodes within the genus *Tilapia s.s.*. However, basal and terminal nodes within the mouth-brooding clade are additionally highly supported by transitional substitutions (compare Figures 3 and 4).

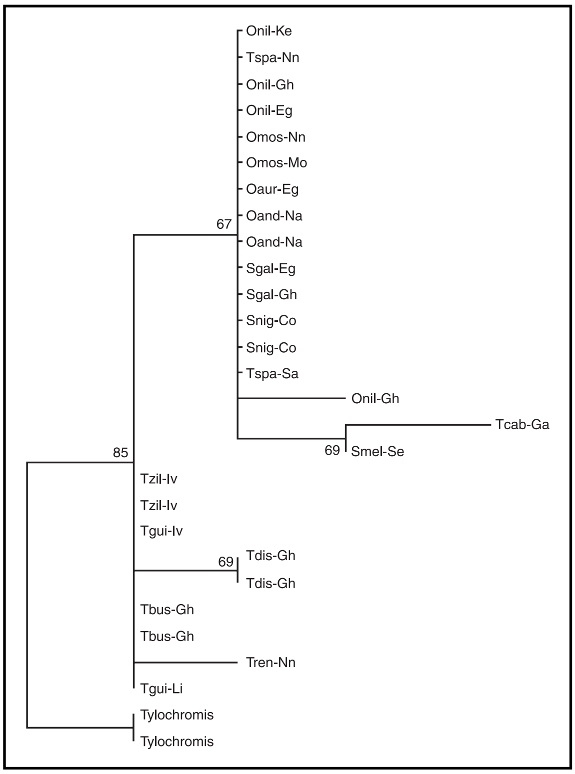

Figure 2. Rooted minimum-evolution phylogeny of the 26 different cyt-*b* haplotypes. Divergences were estimated based on the two parameter models of Kimura (1980) considering 1st and 2nd positioned transversions only. Bootstrapping comprised 1000 replicates. For abbreviations compare Table 1.

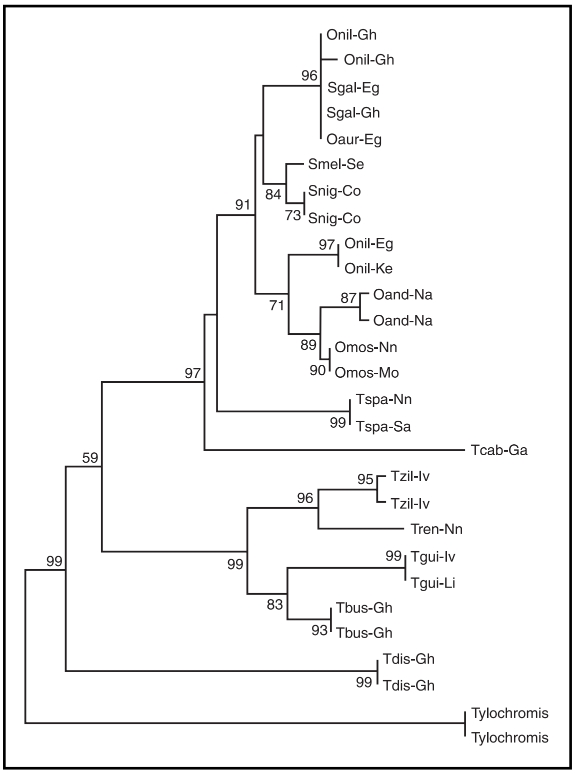

Figure 3. Rooted minimum-evolution phylogeny of the 26 different cyt-*b* haplotypes. Divergences were estimated based on the two parameter models of Kimura (1980) considering 1st 2nd and 3rd positioned transversions only. Bootstrapping comprised 1000 replicates. Abbreviations: Table 1.

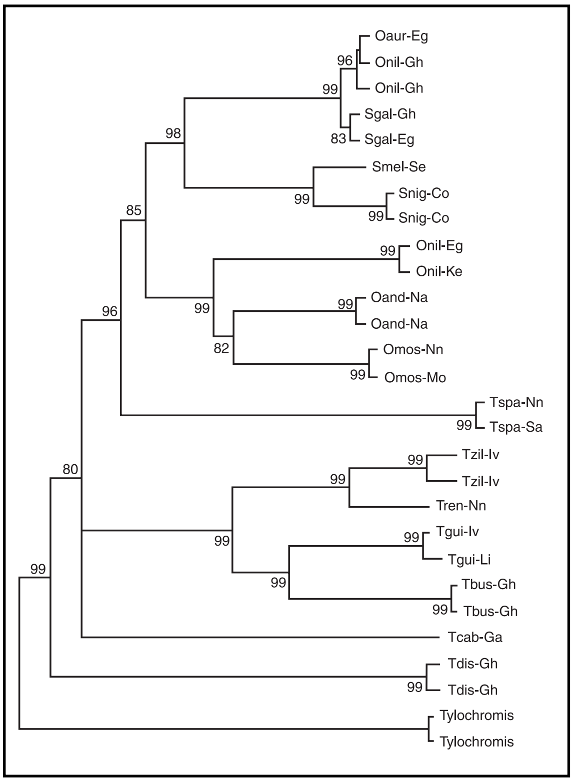

Figure 4. Rooted minimum-evolution phylogeny of the 26 different cyt-*b* haplotypes. Divergences were estimated based on the two parameter models of Kimura (1980) considering 1st 2nd and 3rd positioned transversions and transitions. Bootstrapping comprised 1000 replicates. For abbreviations compare Table 1.

It should also be noted that the validity of nearly all taxa appears highly supported based on cyt-*b* analyses (see bootstrap support of terminal nodes). Only West African *O. niloticus* and Egyptian *O. aureus* specimens were found to share a common cyt-*b* haplotype (Fig. 4). Two reasons may be given for this finding. MtDNA haplotypes of common ancestors of these taxa may have been substantially polymorphic and both species retained a similar haplotype during evolutionary time scales. Secondly, introgressive hybridization events followed by horizontal mtDNA transfer may have occurred. Rognon and Guyomard (2003) demonstrated such mitochondrial DNA transfer from *O. aureus* to *O. niloticus* in West Africa.

Finally, mtDNA sequence divergences between tilapiines may potentially be used to estimate divergence time. Substitution rates determined for vertebrates range from 8% to 20% per million years (Vigilant et al. 1989; Quinn 1992; Slade et al. 1994). However, evolutionary substitution rates of mtDNA in fishes and other poikilothermic vertebrates are known to be substantially slower (Kocher et al. 1989; Canatore et al. 1994; Caccone et al. 1997). Considering molecular clock calibrations established for the cytochrome *b* gene of marine fishes (1-1.2% per million years; Bermingham et al. 1997), mouth-brooding tilapiine taxa diverged from substrate spawners about 8 to 12 million years ago. Accordingly, major diversification processes within the mouth-brooding lineage could be dated back to about 4 to 6 million years.

In conclusion, results so far clearly indicate a potential utility of cyt-*b* analyses to study the phylogeny of African tilapiines. Rooted phylogenies suggest a basal position for species of the genus *Tilapia s.s.* and further support a monophyletic origin of the species of the genera *Oreochromis* and *Sarotherodon*. However, no support was found for the validity of both mouth-brooding genera, e.g. *Sarotherodon* and *Oreochromis*.

Cyt-*b* sequence studies may thus reveal interesting perspectives concerning the phylogeny of African tilapiines and moreover, the systematic status of a variety of tilapiine taxa.

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Session II: Summary, General Discussion and Conclusions

The first paper focused on the genetic architecture and the new taxonomic arrangements within the black-chinned tilapia complex and its implications for the management and conservation of aquatic genetic resources. It clearly outlined the importance of the identification of priority conservation areas (centers of highest genetic diversities within *S. melanotheron*, *S. nigripinnis* and *T. guineensis*), a model study for biodiversity management. At a different evolutionary level, similar studies were presented for the Nile tilapia of the Volta system.

The third paper show-cased the important laws, institutional mechanisms and environmental changes and their impacts in Egypt as well as needs of tilapia aquaculture.

The paper on South Africa reported on the impacts of *O. niloticus* as well as on the resurgence of interest in highly profitable catfish culture and the lack of effective controls of alien species.

The paper presented by Mr. Adyakwa compared the early life history performance of Ghanaian *S. melanotheron* populations. Insignificant differences were reported but indications of different performance in different systems were reported.

The paper presented by Mr. Attipoe compared growth performance of different *O. niloticus* populations from Lake Volta.

The last paper presented in the session reported on the performance of *S. melanotheron* in cage culture in Lake Ayeme. Mr. Ouattara observed good growth rates for this species in this freshwater environment.

Dr. Pullin: Can anybody enlighten us on what exactly happened with *S. melanotheron* culture in Côte de Ivoire because that was an indication of the real potential of the species in a system where there was extensive feeding and where there was also access to lagoon bodies in the pens. I understand that this is no longer operational now and the fish used are now unavailable.

Dr. Abban: This operation has stopped after Dr. Agnese left.

Prof. Blay: Actually we had some cage culture trials for *S. melanotheron* and got encouraging results; fish attained good sizes within 4 months and grew much faster than those in the lagoons. However, the trials failed to get the final data as it was not only the researchers who were monitoring the growth of the fishes. By harvesting time, there were no tilapia left in the ponds.

Prof. Obiekezie: There is a need to have studies (and information) on the pathology and prevention of diseases in the species. Diseases in aquaculture species in ponds can wipe out the whole population.

Prof. Ayinla: We should try to have concerted efforts on the production of good quality *S. melanotheron* fish seed, and have research efforts on the preparation of feeds for the species.

Dr. Pullin: There is a need to know what fishes are good for aquaculture in this region, is it fish that grow very big or fish that grow fast? More market studies may be needed.

Dr. Abban: Maybe fishes which grow fast in order to harvest in shorter time is what is needed. The socio-economic status of the people of the area is one of the main determinant of the sizes of fish they can afford.

Dr. A. Diallo: In Senegal, for example, people in the south prefer small fish, while those in the north prefer big fish.

Dr. Pullin: We need to synthesize the various results of studies on *S. melanotheron* in the region and maybe check to what extent organizations in the region are prioritizing research on *S. melanotheron*.

Dr. A. Diallo: We should join efforts to develop and promote semi-intensive and intensive aquaculture of *S. melanotheron* in brackish and marine waters.

Prof. Ayinla: Efforts should be intensified in genetic selection for development of good quality seed. It is also important to develop cost-effective feed. There should be a concerted research effort for the culture of *S. melanotheron* in brackish water systems. And since *S. melanotheron* is suitable for brackish water, no research effort should be made in attempting to acclimate it to freshwater culture.

Dr. A. Diallo: One way of promoting fish conservation is to enact a good fisheries code such as the FAO code. The other way is to promote the sustainable development of aquaculture of new species and/or over-exploited species.

Dr. Dugan: It is important to see this workshop as a potential platform for continuing a range of work on this issue in the region in the future. However, funding for this may come from agencies that are concerned about either conservation or use of biodiversity for meeting economic needs. It is important that research be carried out to contribute to very clear proposals on how best to conserve biodiversity and how best to use that biodiversity to meet socio-economic needs.

Recommendations and future requirements to conserve African fish biodiversity and maximize potential for future use

- Expand biodiversity and genetic characterization studies in West African areas on species with potential for fisheries and aquaculture;
- Use management approaches based on the information of such biodiversity studies;
- Focus on efficient in vivo conservation efforts: identification of priority conservation areas;
- Culture species in environments that are close to their natural environments; and
- Promote sustainable aquaculture.

Problems and opportunities for aquaculture of *S. melanotheron/ S. nigripinnis*

- There are indications of good performance in freshwater of *S. melanotheron*. It is highly recommended that aquaculture trials in this environment be pursued.
- The high performance Ivoirian strain (origin Senegal) is kept at the University of Montpellier (France) following closure of the Ivoirian farm. This may be used as a source for future strain development.
- There is a need to research markets for small fish and larger fish so as to design culture systems to supply both types of demand.
- There is also a need to share results of *S. melanotheron* culture trials regionwide.
- There is a need to develop better *S. melanotheron* strains for brackish and freshwater culture, subject to ensuring biosafety.

Session III

Fish and Fisheries Resources: Utilization and Conservation

Chair: Prof. Ayinla

Resources and Constraints of West African Coastal Waters for Fish Production

Philippe A. Lalèyè
Laboratoire d'Hydrobiologie et d'Aquaculture.
Faculté des Sciences Agronomiques de l'Université d'Abomey Calavi. 01 B.P. 526 Cotonou, Béni

Jacques Moreau
Dept. of Tropical Fisheries, I.N.P. / E.N.S.A.T. B.P. 107, Auzeville Tolosane, 31 326 Castanet Tolosan, France

Brackish waters are regarded as some of the most productive aquatic ecosystems in the world, and are of great socio-economic importance (Kiener 1978). This paper presents the importance of resources for and constraints on for fish production in brackish waters of West Africa. It also outlines the main aspects of better management of biodiversity in brackish water ecosystems in West Africa.

In the tropical zones and particularly in West Africa, brackish waters are abundant in the Atlantic Ocean littoral, within the limits of the Gulf of Guinea. From Ivory Coast to Nigeria, their total surface area is about 3 140 km² (Table 1). Their aquatic resources are highly diversified and intensively exploited by ever growing riparian human populations (density between 3.5 inhabitants km^{-2} near Aby Lagoon in Ivory Coast and 96.5 inhabitants km^{-2} near Lake Aheme in Benin).

Table 1. Surface of tropical West African lagoons

Coastal lagoons	Surface (km²)
Liberia	112
Ivory Coast	1 268
Ghana	434
Togo	64
Benin	325
Nigeria	937

Resources of West African lagoons

The exploitation of West African coastal waters concerns mostly fish (Cichlidae, Claroteidae, Clupeidae…) and Crustaceans (Peneids Shrimps and Crabs). The fish fauna and its diversity are seasonally variable in relationship with the entrance of marine waters into the lagoons. It can be divided into three categories of fish communities according to Durand et al. (1994): (1) the littoral euryhaline marine species which come seasonally or accidentally in the lagoons; (2) the estuarine species which live usually in mixohaline inland waters; and (3) the continental or inland water species which are only scarcely recorded in the lagoons as they can enter them only when the water becomes fresh when rivers flood (Daget and Iltis 1965).

In Ivory Coast, a total of 153 species belonging to the three categories of fish indicated above have been recorded in the whole lagoon system (Albaret 1994). More than 100 species are also known from Benin lagoons (52 species in Lake Ahémé, 68 species in Lake Nokoué, 72 species in the Porto Novo Lagoon (Lalèyè et al. 1995; Lalèyè and Philippart 1997). In Nigeria, 79 species have been identified in the Lagos Lagoon. Several species are common to these lagoons. The most abundant species are: *Sarotherodon melanotheron*, *Tilapia guineensis*, *Hemichromis fasciatus*, *H. bimaculatus*, *Ethmalosa fimbriata*, *Elops lacerta*, *Mugilids* (*Mugil* spp. and *Liza* spp.), *Chrysichthys nigrodigitatus* and *C. auratus*, *Pomadasys* spp., *Gerres nigri* and *G. melanopterus* and *Caranx hippos*.

Crustaceans are represented mostly by *Penaeus duorarum*, *Callinectes latimanus*, *Goniopsys cruentata*, *Cardiosoma amatum* and *Clibernhardius africanus* (Burgis and Symoens 1987).

Production of West African brackish waters

Fishing techniques in the lagoons are numerous. Cast nets, drag/seine nets, gill nets of various mesh sizes, long lines and traps are commonly used (Weigel 1985; Koranteng et al. 2000). A specific production approach is the "acadja" system, which was initiated in Benin more than 100 years ago. The acadja system aims at providing additional substrata on which food for fish would develop (Welcomme 1972). Catch in acadja systems are relatively high, ranging from 86 kg/ha^{-1} yr^{-1} in Lekki Lagoon, Nigeria to 1 tonne ha^{-1} yr^{-1} in Lagoon of Benin. Table 2 shows catch and yields of fish in various West African Lagoons. The high production recorded in Benin is partly due to the development of acadjas in the country. For other countries, e.g. Senegal, Gambia, Ivory Coast, Ghana, Togo, Benin and Nigeria, the average productivity of lagoons and estuaries is around 290 $kg.ha^{-1}.yr^{-1}$. The actual catch and its compositio have changed over the years in several lagoons for various reasons. When time series of catch are available, it appears that catches are highly variable from one year to the other.

Constraints on fish production

In some lagoons such as in Ivory Coast, catches are decreasing with time not only due to overfishing but also because of prohibition of beach seine and purse seine net. In some other lagoons, actual catch is changing in relationship with the frequency of the connection with the sea.

In several cases, the number of exploited species and the average size of first capture are simultaneously decreasing because of long-term use of small mesh size net despite legislation. The recent impact on fish communities of pollution and simultaneous eutrophication has also to be considered even though they have not been documented well (Laleye et al. 1993).

Suggestions for better management of West African brackish waters resources

Generally, collaborative strategies should be implemented for a sustainable management of the aquatic resources of the lagoons and development of the region. From this point of view, mangroves should be rehabilitated on a regional basis and fishing legislations should be harmonized in order to avoid over-exploitation of lagoons one after the other by migrating fishermen. A particular point is to manage connections with the sea so as to increase biodiversity and production. Biodiversity has also to be protected by water purification designs in order to decrease discharge of wastes coming from large cities. A sensitization-education program for

Table 2. Current information on catches of some West African lagoons (from Adite and van Thielen 1995; Durand et al. 1994; Laë 1992,1994; Laleye et al. 1995)

Water bodies	Year of reference	Catch	Yield	Main exploited species
Ebrié	1985	3 000	71	*Ethmalosa fimbriata* (33%), *Chrysichthys* (11%), Elops (10%), Tilapias (8%)
Aby	1985		215	idem
Keta Lagoon	1988	4 000		*Sarotherodon melanotheron* (90%),
Sakumo Lagoon	1995	508		*Sarotherodon melanotheron* (90%)
Togo Lagoons	1989	2 260	400	*Liza falcipinnis* (35%), *Caranx hippos* (21%), *Sarotherodon melanotheron* (10%), *Chrysichthys* (10%), *Ethmalosa fimbriata* (5%)
Lake Ahémé	1994	4 144	487	*Cichlids* (70%), *Gobiids* (10%), *Chrysichthys* (2%), *Ethmalosa* (5%)
Lake Nokoué	1944	20 000	1 330	*Cichlids* (33%), *Ethmalosa* (7%), *Gobiids* (4%), *Chrysichthys* (3%), *Mugilids* (2%),
Porto-Novo Lagoon	1994	3 442	1 147	*Cichlids* (46%), *Ethmalosa* (13%), *Chrysichthys* (11%)
Todougba and Toho Lagoon	1988	387	256	*Sarotherodon galilaeus* (73%), other *Cichlids* (12%), *Chrysichthys auratus* (7%).

rural populations on sustainable management of aquatic resources should also be elaborated.

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Discussion

Dr. Abban: I would like to know if the speaker or any other participant has records on observations indicating that water development projects (e.g. creation of reservoirs along rivers) have affected brackish waters productivity.

Dr. Laleye: The creation of dams affects water exchange in lagoons. The reduction of freshwater flow into lagoons could lead to formation of barriers on sand bars which could limit the influx of marine fishes into lagoons and consequently reduce fish production.

Dr. Agbleze: In response to Dr. Abban's concern, reports from local communities indicate that the Keta Lagoon located in the coastal Savanna zone has been experiencing more frequent dry-outs after the creation of numerous dams upstream of rivers feeding the lagoon for agricultural purposes.

Dr. Agbleze: In Dr. Laleye's presentation, *S. melanotheron* dominates the catches, what is the patronage for *S. melanotheron* in the West African sub-region as food fish compared to other species in the catches?

Dr. Laleye: There is a high patronage for *S. melanotheron* all over the West African Coast.

Dr. Pullin: It looks as if all the fish catches in West African brackish waters are made up of native species, not alien species. There have been some introductions of alien, saline-tolerant tilapias, e.g. *Oreochromis aureus* and *O. mossambicus*, for aquaculture research development projects in the lagoon areas of Côte d'Ivoire – but these alien species did not seem to have established there. Maybe there is some difference between the numbers of alien species introductions that result in establishment in brackish waters vs. those in freshwaters. This could be checked in the introduction table in FishBase.

Dr. Agnese: Introduced species are typically freshwater species. With respect to lagoons there seems to be no alien species that is well adapted to brackish water conditions, hence the reason why no alien species have been introduced and established in lagoons.

Prof. Ayinla: What is the input of research on the Acadja system in Benin? What type of fish is being used in the Acadja system? Is there a way research can intervene to further improve production in the Acadja system by introducing a particular species?

Dr. Laleye: Some research has been done and the results are available in the proceedings of the previous workshop. No particular species is used in the Acadja system since it attracts all types of species. The principal fish in the lagoons is *S. melanotheron* and it forms about 60% of the catches from the Acadja system.

Fish Resources Utilization and Conservation Measures in Niger

A. Harouna
Direction Faune-Pêche-Pisciculture, B.P. 721 Niamey, Niger

Niger is a 1 276 000 km^2 landlocked country with 10 million inhabitants. Seventy-five per cent of the country is desert. Livestock, agriculture, and fisheries are the most important rural activities. Fisheries contributes 10 billion CFA franc to the national economy per annum.

Of the 98 fish species reported in the country, 22 are of economic importance. Fish production varies between 2 000 t and 20 000 t. These fluctuations are mainly due to variations in annual rainfall and problems of access due to water hyacinth. Tilapias represent 20% of all captures and the price per kilo varies from 500 to 1 500 FCFA.Some breeding programs for tilapia have been set up. The first trials were made in 1982 with financial help from France. Tilapias, mainly *Oreochromis niloticus*, were raised in cages. Performances were good but cost of production per kilo was high due to high cost of fish proteins imported from Côte d'Ivoire. The improvement of fish culture in Niger thus depends on the lowering of food input costs as well as the availability of water due to the severe drought that the country faces.

Discussion

Dr. Laleye: In your presentation of fish production statistics, fish production is apparently still increasing. Does it mean that the resources are under exploited?

Dr. Harouna: Yes, because the techniques used are not developed. If the techniques become sophisticated, which cannot be ruled out with time, the resources will be over-exploited. There is also the problem of water hyacinth which can affect production.

Dr. Kabre : What is the role or function of intermediate agents, e.g. Forestry agents, in the production and conservation of fishes?

Dr. Harouna: The role of such agents have essentially to do with monitoring and the enforcement of legislation.

Dr. Sakiti: Is *Azolla* used in the culture of fish in Niger?

Dr. Harouna: Not yet but we are interested in the results of research on Azolla done by your laboratory.

Development Project of Aquaculture in the Republic of Guinea

Mody H. Diallo
Division Peche Continentale et Pisciculture
Conakry, Rep. of Guinea, BP: 307

This pilot project has been funded by the Agence Française de Développement, AFD, (750 000 Euros) and has been executed in the forest region of Guinea (Guinée Forestière) by the Directorate for Inland Fisheries (Direction Nationale de la Pêche Continentale) with technical assistance from AFD. The project aims to demonstrate the potential for aquaculture in the forest region, to enhance the food security in this region and to provide an alternative source of income for the farmers. Extensive polyculture was adopted for a three to ten-month cycle with male *Oreochromis niloticus* as the primary species (60% of the population), *Heterotis niloticus* (20%), *Heterobranchus isopterus* (15%) and *Hemichromis fasciatus* (5%). Twenty-five farmers have been trained and equipped with necessary seed. Today, they are able to evaluate the qualities and possibilities offered by any stream and site, follow the construction of their dam, manage the water flows, determine the sex of their tilapias, improve cash income and improve the availability of fish on the local markets. Farmers now have a better knowledge of the financial management of their activities. It is intended that the project be extended by a second phase project that should start in early 2003.

Phenotypic Variation in African Freshwater Fishes: A Geographical Scale Review

D. Paugy and Y. Fermon
Laboratoire d'Ichtyologie Générale et Appliquée, Museum National d'Histoire Naturelle
43, rue Cuvier, 75231 Paris Cedex 05, France

The adaptation of fishes to environmental constraints is slower compared to some invertebrates, but the phenomenon exists in both temperate and tropical zones.

In the tropical zone, several examples showing the influence of feeding habits on morphological variations in fishes exist. The existence of dwarf populations that mature at a smaller size than usual is recorded for various tropical species and generally dwarf forms are associated with lacustrine conditions. Changes in environmental conditions may also influence the biological cycle of species. With respect to reproductive strategies, some ubiquitous species may modify their spawning period to adapt to changes in environmental conditions, mainly changes in the hydrological cycle.

The gradual development of a series of small morphological differences between neighbouring populations of a widely distributed species, or clines, are generally responses to environmental conditions. When such populations are isolated, however, and when there is no gene flow between the populations, specialization may occur. The most famous example is that of the numerous species flocks of the Great Lakes of East Africa.

The paper shows that phenotypic variations in African fishes may exist at each geographical scale, and examples are given on morphological or biological variations covering local areas and the complete African inter-tropical zone.

Discussion

Dr. Olaleye: There were no data presented on the Niger/Benue system and I know the system has most of the species presented and more. Can you explain why there is that gap?

Dr. Fermon: Only a few examples were presented because of the time constraints.

Dr. Abban: What environmental characteristics have been considered to be associated most with the morphological or meristic variations and clines observed along a water system?

Dr. Fermon: It is difficult to say because there are many environmental variations – a lot of things come into play.

Dr. Falk: You presented several examples on morphometric variations within African fish species over a broad geographic scale, and concluded that these variations are caused by environmental conditions. However, for a variety of species it is known that they cover very distinct and differentiated genetic units. I really doubt that you can, therefore, relate morphological variations to environmental clines only. Genetic differences between different geographical units have to be considered as well. You have to be very careful with this kind of interpretation when you are dealing with isolated, genetically distinct organisms, even if you are dealing with populations of the "same" species.

Dr. Pullin: Morphometrics and other techniques (such as biochemical genetics) will become increasingly important in resolving whether a given population or individual is "distinct", in the sense of the terminology of the convention on biological diversity. For farmed species, the country in which populations or individuals acquire "distinct" characteristics is considered to be their country of origin. For wild species, distinct genetic resources (such as subspecies) are also important to the countries that own them. This suggests that taxonomic splitting has some utility in assigning ownership/benefits. But lumping clinal extremes does not help here. The important point is "genetic distinctness".

Thermal Influences on Sex Determination of Natural Populations of Nile Tilapia, *Oreochromis niloticus*

Etienne Bezault
Laboratory of Fish Genetics, INRA
& Aquaculture Research Unit, CIRAD-EMVT
Montpellier, France

Within the tilapias, species of major importance for tropical aquaculture, studies on the control of sex determination and reproduction are very important with regard to the improvement of monosexing methods. This concern includes the Nile Tilapia, *Oreochromis niloticus*, natural populations of which are widespread from the Nilo-Sudanian systems to the north of the East African Rift, and show an important ecological plasticity. Previous studies have demonstrated that in tilapia, sex is determined by major (XY or ZW) and minor (autosomal) genetic factors and influenced by environmental temperatures. High temperatures (32-36°C) applied while fishes are in their undifferentiated stage can promote masculinization in some offsprings. Under natural conditions tilapia fry may partly be exposed to such thermal conditions which may potentially influence their sex. However, previous studies were only done on aquaculture strains and under controlled conditions, so masculinization under natural conditions has never been observed. This thermal sensitivity of sexual differentiation may represent an interesting adaptive reaction.

In this project *in situ* (in natural and semi-natural/ ponds conditions) and *ex situ* (strictly controlled ones) studies have recently been started on the potential thermo-sensibility of different natural populations of the Nile Tilapia subjected to different extreme thermal conditions: constant cold temperature habitats, constant hot temperature habitats and habitats with a large thermal range. Studies were carried out in two African countries. In Ethiopia, habitats with two extreme thermal conditions were chosen: (1) hot water springs of the Rift Valley, in which water temperature can reach 43°C, and (2) the cold water crater lakes related to the Awash system, in which the temperature is maintained below 25°C. The populations living in these two habitats are genetically closely related. Secondly, the Volta system in Ghana has been chosen to study populations living under conditions with a wide thermal range.

Because of the strong social and reproductive behaviour and the importance of spatial structuring of populations and life-stages, we are starting to analyze the genetic structure and sex ratio of fry schools in comparison with their potential population to understand the biological nature of such schools and the importance of thermal conditions on the sex ratio.

This project aims to evaluate the adaptation of different natural populations of the Nile Tilapia to extreme thermal conditions, in particular with regard to their sexual differentiation under natural conditions. Growth and reproduction strategies of individuals from these populations will be characterized to estimate the potential use of the thermal sensitivity of sexual differentiation. Finally, the present project exemplifies research and use of biodiversity which may suggest new approaches for the control of sex and thus the improvement of local aquaculture.

Discussion

Dr. Falk: What I am going to say is similar to the comment I have given to Dr. Fermon. You tried to demonstrate that sex ratios in different populations of the Nile tilapia may be based on thermal differences only. However, as we know, several of these populations are genetically completely isolated and also very distinct. It is, therefore, not possible to conclude that temperature effects exclusively are responsible for variations in sex ratios. If you want to demonstrate such effects, you should focus your work on genetically homogenous strains, for example. Otherwise, you cannot exclude that these differences are also based on different genetic compositions of isolated populations.

Mr. Bezault: We did not check the genetic aspects because a lot of genetic traits are adapted to specific conditions. We want to study only the environmental aspects.

Dr. Rezk : Life history of each species can influence the morphology of the species. It is also important to relate genetic differences with morphometric differences.

Mr. Kwafo Apegya: What is the sex ratio that can be achieved at the maximum temperature of 36°C?

Mr. Bezault: Above 32°C, depending on the breeder, one can achieve either 100% or 50% males.

Session III: General Discussion and Conclusions

Dr. Olaleye: Priorities should also be accorded to inland impoundments which could be harnessed for fish production. *S. galilaeus,* which is the dominant reservoir tilapia and endemic to inland impoundments in Nigeria, should also be considered a likely candidate for genetic improvement and subsequent culture for enhancement of tilapia fisheries in inland waters.

Mrs. Adeogun: I would like to see resources management policies developed which will involve all the West African Coastal stakeholders based on common property philosophy devoid of anglophone/francophone dichotomy.

Dr. Pullin: Plan for the future expansion of aquaculture and for addressing the new situations that this expansion will bring for conservation of biodiversity and genetic resources. The expansion of aquaculture will increase the possibilities of interactions between farmed animals and wild animals. Farmed animals become progressively genetically altered from their wild relatives, i.e. domesticated. Planning research is needed to identify approaches, institutions, costs etc. for ensuring that aquaculture expansion and conservation of farmed and wild genetic resources proceed together with adequate funding for both.

Dr. Rezk: An area of great importance for research is to identify what the diversified populations we identify are good for. That is to say, it is important to relate the molecular genetic differences between populations not just to morphometric and meristic traits but to performance traits needed in different aspects that the fish can be used for, e.g. aquaculture and fisheries, or as ornamentals.

As indicated in my presentation about the situation in Egypt, there is a concern about the expansion of aquaculture and the impact of escapees from aquaculture facilities on natural populations. This is an important area, in my opinion, for future research.

Dr. Laleye: The problem of aquaculture is the cost of feeds for fish. Importing fish to feed fish is very expensive and costs too much for aquaculturists. The solution would be to progressively use the local resources to prepare fish food.

Dr. Falk: Looking at the literature and listening to the discussions here, it is very clear that only limited information is available on the biodiversity of West African fishes. Very few genetic studies on broader geographic scales have been conducted so far and the vast majority dealt with, lets say, five species with potential for fisheries and aquaculture. In fact, even most of these studies are provisory. What I would like to recommend from this point of view is to try to:

- Expand biodiversity studies on West African fish species, in particular on those with broad distributions;
- Monitor fish biodiversity in West Africa;
- Establish training opportunities and programs for West African professionals in characterizing fish genetic resources;
- Implement these data into conservation and management strategies;
- Define conservation and management strategies for West African fishes on all available biological data, including systematic and genetic knowledge on these species; and
- Include research on the socio-economical and socio-ecological aspects of conservation and management.

Mr. Bezault : We can add:

- Limit as much as possible the introduction of exotic gene pools: GMO's, exotic species, sub-species, improved strains;
- Improve knowledge on the biology of fish at the local level (i.e. ecology, physiology, behaviour, morphology, parasitology and diseases resistances);
- Improve first, the development of populations adapted to local specific conditions with improvement of culture methods; and
- Develop comparative methods for analyzing physiological traits of major importance (growth, salinity tolerance, sex).

Recommendations for West African tilapia genetic resources research

Future research priorities and related items:

- Expand and complete biodiversity studies on West African fish species on a broad scale, focusing on species of current importance for fisheries and aquaculture;
- Emphasize human resource capacity building and strengthening of established laboratories in the region, including international collaborations;
- Establish training opportunities and programmes for West African professionals in characterising fish genetic resources;
- Evaluate the current status of introduced alien species in West Africa and their implications with regard to biodiversity conservation;
- Improve and study populations adapted to local conditions instead of blindly using exotic populations/strains and introducing these to "new" environments;
- Expand research on the genetic basis of important traits (growth, salinity tolerance) for aquaculture;
- Extend genetic studies from cultured fish to wild populations with which they might interact;
- Determine the reaction of fish to (climatic) variation;
- Analyze the influence of structures (connections, reservoirs, dams etc.) on movements of marine and freshwater fishes and the implications on faunal changes;
- Increase the production and quality of fish (seed);
- Determine the range of market (eco-friendliness), risk assessment and ecological barriers;
- Increase the quality, availability and linkages of information; and
- Revise legislation.

Recommendations for Conservation:

- Try to preserve biodiversity at all hierarchical levels (ecosystems, species, populations, genes); and
- Limit introductions of exotic gene pools.

General suggestions for management (sustainable utilization and conservation):

- Improve the knowledge on biology (ecology, physiology, behaviour, morphology, genetics, parasitology, disease resistance, etc.) at the local level; and
- Preserve/protect sensitive habitats (e.g. mangroves) on a regional basis and harmonize legislation.

Session IV

International Perspectives

Chair: E.K. Abban and J-F. Agnèse

International Concerns on Fish Biodiversity Conservation in Africa

Roger S.V. Pullin
7A Legaspi Park View, 134 Legaspi St., Makati City 1229, Philippines

"Use" and "conservation" of renewable natural resources are widely (and wrongly) perceived as conflicting objectives. Foregone extractive use, for conservation, is viewed as a sacrifice, but the greater sacrifice (for future users) is to forego conservation. Conservation is itself a form of non-extractive use: insurance for continued production. "Use it or you lose it" certainly applies to fish biodiversity, but without conservation the result becomes "abuse it as you lose it".

Fisheries management has generally failed to combine extractive use of biodiversity with effective conservation. Despite global ratification of international conventions and codes of conduct and increased environmental awareness, there is often a "disconnect" between biodiversity policy and food policy. Biodiversity, at genetic, species and ecosystem levels, is widely regarded (particularly by urban dwellers) as something "out there"; part of "Nature"; not as the source of all human food: biodiversity on the plate, the products of ecosystem goods and services.

Moreover, there is limited acceptance of the principle that exercising *rights* to food, to biodiversity and to natural resources in general also places conservation *obligations* upon users, including consumers. Electorates and their elected generally place responsibilities for biodiversity and for fisheries/aquaculture in different hands and under separate budgets. Following the money means working on extractive use rather than conservation and there is little intersectoral cooperation. The results include overfishing, boom-and-bust aquaculture, and biodiversity/ environmental mismanagement.

Against this global background, international concerns for use and conservation of the fish biodiversity of Africa are broadly similar to those elsewhere, but are greatly exacerbated by chronic and severe problems: poverty and indebtedness; disease; climatic uncertainties; political instabilities and civil strife. These impose upon rural and urban populations a daily struggle for survival that precludes much attention to effective management of fish biodiversity. Moreover, they attract some politicians and entrepreneurs to "quick fixes", such as introductions and transfers of alien species and biotechnology, sometimes without adherence to international conventions and codes of conduct, risking adverse environmental impacts.

As solutions to these basic problems *must* emerge in a more equitable world, increasing international and national/local support must also be provided to assist the evolution of effective use and conservation of fish biodiversity in Africa. Given such support, the following general objectives are suggested.

- **Monitor** as fully as possible and at all levels (genetic, species, ecosystem) the true status and trends of conservation and use of fish biodiversity in Africa.

- **Provide** wide and continuous access to this information, without censorship, exaggeration or other manipulation.

- **Educate** the general public and professionals concerned about the present and future contributions of fish biodiversity to food supply and livelihoods, emphasizing human dependence upon, as well as the obligations that accompany human rights to use, fish biodiversity.

- **Establish** institutional changes for combining policies, responsibilities and budgets for the use and conservation of fish biodiversity in Africa, and for intersectoral partnerships.

Discussion

Dr. Rezk: I fully agree that any farmed stock is "altered" but there is an important difference between a tilapia that has only tilapia genes that are in a favorable arrangement and a tilapia that has non-tilapia genes. We all agree that we have to go on with improvement of production quality and quantity and there is an array of techniques available. If there is a line to be drawn between what is clean and safe practices and what is not so clean, where do you think it can be done?

Dr. Pullin: The process of production of an organism does not matter but rather how it will interact in the environment it has access to. How it will behave after it has been produced is of more importance. There is the need for a very clear policy on biosafety and conservation. Whatever technique you use should have a parallel program for conservation and biosafety and you need to measure the progress towards the objectives of both and fund them together.

Mrs. Taiwo: Are there suggestions for scientists in countries facing the problems of "disconnect" in the food sector and other natural resource dependent sectors being organized, regulated and financed separately and their failure to fulfill obligations while exercising rights to use renewable natural resources?

Dr. Pullin: The scientist needs to lobby hard for people in authority to realize the importance of their work on biodiversity. This will elevate the debate on biodiversity to that of food security. It will be necessary to get some politicians or NGOs on board and convince them of the importance of biodiversity.

The Nairobi Declaration on Conservation of Aquatic Biodiversity and Aquaculture in sub-Saharan Africa: Implications for Research on *Sarotherodon melanotheron*

Patrick Dugan
The WorldFish Center, Regional Center for Africa and West Asia, Abbassa, Egypt

Introduction

Fish is a critically important source of animal protein to the people of Africa, and aquatic resources play a central role in sustaining rural and urban livelihoods across much of the region. Yet for the continent as a whole the per capita supply of fish is declining and current projections of supply and demand indicate that this gap will continue to grow in the coming decades.

If this gap is to be bridged capture fisheries need to be sustained and the potential of aquaculture realized. In doing so the rich aquatic biodiversity of Africa needs to be protected, especially the rich diversity of freshwater fish that sustains capture fisheries and provides species for aquaculture.

In recognition of the importance of Africa's fish biodiversity, and of the potential threats to this from the development of aquaculture, an Expert Consultation on Biodiversity and Environmental Impact of Genetic Enhancement and Introduction of Improved Tilapia Strains and Alien Species in Africa was convened in Nairobi, Kenya in February 2002 under the auspices of the WorldFish Center, CTA, FAO, IUCN – The World Conservation Union, UNEP, and the CBD, to discuss and develop guidelines that will foster the development of aquaculture while maintaining biodiversity. The meeting, which was attended by aquaculturists, geneticists and conservation specialists from Africa, produced the "Nairobi Declaration on Conservation of Aquatic Biodiversity and Use of Genetically Improved and Alien Species for Aquaculture in Africa".

The Nairobi Declaration

The Nairobi Declaration recognizes that there is considerable potential for improving the performance of fish species and strains used in aquaculture in Africa. Equally, however, it recognizes that there is a clear risk of escape of these improved strains into the wild, and possible negative impacts on biodiversity. If the full potential for sustainable aquaculture in Africa is to be realized, these concerns need to be addressed. In recognition of these concerns the Declaration set out 10 Recommendations.

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

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

3. **Responsible introductions.** Introductions of fish, including genetically improved (altered) strains and alien species, may have a role in the development of aquaculture. Any movement of fish between natural ecological boundaries (e.g. watersheds) may involve risk to biodiversity and there is need for refinement and wider application protocols, risk assessment methods, and monitoring programs for introductions of fish, including genetically improved (altered) species and alien species. States have important responsibilities in the development and implementation of such protocols and associated regulations, the establishment of clear roles and responsibilities, and capacity building. Such efforts should be linked to obligations pursuant to the Code of Conduct for Responsible Fisheries, the Convention on Biological Diversity, and other relevant international agreements.

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

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

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

7. **Controlling pathogen movement.** Internationally accepted codes and protocols for reducing the risk of transboundary movement of pathogens (including parasites) through movement of fish including alien species do exist, but they do not address any specific needs regarding genetically improved (altered) species. States and other relevant bodies should evaluate the existing codes and protocols for reducing the risk of transboundary movement of pathogens (including parasites) through movement of fish including alien species and genetically improved (altered) species, and adapt them for African conditions.

8. **Raising awareness of risks of fish introduction.** Policy makers, enforcement agencies, stakeholders and the general public need to be made aware of issues related to, and the need for, policy on the movement of alien species and genetically improved (altered) species, and this should be high on national agendas.

9. **Engaging stakeholders.** Some policies relevant to the movement of fish seem difficult to implement, are unknown to users, create conflicts of interest, or are viewed as restrictive, in part because they have been developed with limited consultation and participation. Formulation of policy and legislation concerning fish movement should seek to engage all stakeholders in a participatory process. In addition, governments should establish advisory groups with links to independent and scientifically competent expert bodies such as FAO, IUCN, and the WorldFish Center.

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

Importance for *Sarotherodon melanotheron*

The Nairobi Declaration has many important implications for future research concerned with the use of Africa's fish biodiversity in aquaculture. I would like to highlight five here.

1. **Understand the range of constraints and focus on the most important.** It is essential that future research into the use of *S. melanotheron* and other suitable species focus on the most important constraints faced. While research on ways to improve aquaculture performance is clearly needed, this needs to be pursued in conjunction with research to address other priority constraints. This will, in particular, require research on markets and production economics of *S. melanotheron* and other species, and on social and institutional constraints to aquaculture.

2. **Provide improved quality seed.** Sustained production of good quality seed for aquaculture is a widespread problem in sub-Saharan Africa. Ways to overcome this need to be developed. Good management of existing broodstock can sustain the quality of seed available for aquaculture without recourse to selective breeding programs to improve the germplasm.

3. **Risk assessment.** If genetic improvement is to be pursued the risks should be assessed. The genetic information required for such risk assessments needs to be specified and research conducted to provide this.

4. **Conserve biodiversity of wild stocks.** In support of more targeted conservation investments, priority populations, areas and ecosystems that support the greatest biodiversity in wild fish stocks should be identified and the conservation actions required to maintain these need to be specified. Further genetic research required to identify these areas should be pursued and attention given to ensuring that this information is used to support conservation.

5. **Strengthen quality, access to, and use of information.** It is crucially important that further research on biodiversity of African fish is used more effectively to strengthen management and policy. Careful attention needs to be given to investing in research that will provide information that will help address specific management and policy constraints, and to ensure that this is disseminated effectively. Too much research is currently of little practical value to management or policy, and much of the information that could be of value is "lost" in unpublished research reports and is consequently of no practical value.

Discussion

Dr. Pullin: FAO is developing an information networking system on fish genetics. Its development is being supported by the Government of Italy. This system will be up and running in 2003.

Dr. Changadeya: The speaker mentioned conserving wild stocks/diversity. My question is how can this be done? What are his suggestions?

Dr. Dugan: The point I made was that there is a very clear message in the Nairobi Declaration that one of the most important things is to identify the most important wild stocks or ecosystems that support wild stocks in the region and identify those as conservation priorities. We then need to invest in managing those so as to sustain as much biodiversity as possible. How that is to be done is a more challenging question and the work we have done within the last two days is in the right direction. Having identified priority regions, the next step is to help ensure that the diversity they support is maintained, including through addressing concerns about alien and modified species and setting up better management of conservation areas. This will need to include consideration of the impacts of changes in waterflow on these systems and the species they support.

Dr. van der Bank: How can WorldFish/FAO help us on the ground level to improve our specific problems?

Dr. Dugan: The Nairobi Declaration alone can only make a small difference on the ground. However, if individual countries decide to address these issues, many institutions including WorldFish will be interested in providing support. We hope that the Declaration can serve as a catalyst for such national action and international support.

A Regional Approach to a Fish Breeding Program for Farmers: Research and Networking Needs

John Moehl
FAO Regional Aquaculture Officer
Box 1628, Accra, Ghana

Problems with fish breeding and seed supply are major constraints to aquaculture development. A variety of approaches have been tried to address this issue; both quantitatively and qualitatively. Recent efforts have attempted to learn from past experiences and formulate sustainable production and delivery mechanisms.

In 1975, the First Regional Workshop on Aquaculture (ADCP/REP/75/1) recommended that government centers be established for production and distribution of inputs including seed, noting "*... in the initial stages, seed production and supply should preferably be developed as a governmental support service to the farmers*". Perspectives changed and by 1988 the Expert Consultation on Aquaculture Planning (ADCP/REP/89/33) stated: "*Government should be assisted to refurbish existing breeding facilities to meet the demand for fish seeds, but a high priority should be given to the production of seeds by the private sector*." With regard to Africa, the Conference on Aquaculture in the Third Millennium (NACA 2001), concluded a lack of seed had "*been a problem constituting a serious restriction to aquaculture development*."

Furthermore, one should not expect governments to resolve this problem. Many government hatcheries no longer have resources to produce, let alone distribute, seed. Farmers depending on government have suffered long waiting periods only to receive poor quality products.

The current focus is based on the 1999 Africa Regional Aquaculture Review (CIFA/OP24) which concluded that 80% of national programs in the region suffered from seed shortages. Key lessons learnt included: (a) centralized and subsidized supply is a disincentive to private sector involvement and creates shortages; (b) seed should be produced locally by farmers; and (c) known-age fingerlings are necessary if good results are to be obtained. It was concluded that it is "*highly probable that actual mixed-sex tilapia systems utilized by a majority of African farmers could be significantly improved if the quality of seed is improved*." The Review recommended: (i) a focus on a limited number of culture organisms, locally available inputs and existing technology; (ii) government infrastructure be reduced as governments disengage from seed production/distribution and shift attention to broodstock management; (iii) regional and national research programs on broodstock management be initiated; and (iv) regional information network be established.

Shifting responsibilities for seed production/distribution and emphasis on quality products raise a series of questions whose answers lie in research. Given the universality of these questions and the commonalities among farmers, regional research programs are most effective. Examples of research topics are: (1) methods for farmer-produced (own) quality seed; (2) requirements for broodstock exchange for private hatcheries;

(3) broodstock population management at government facilities; and (4) age versus nutrition effects on seed quality.

Regional activities addressing common issues have a large constituency. However, information exchange in the region is among the chief challenges confronting many disciplines. Regional research must be accompanied by regional networking if the results are to be worthwhile. Initial networks require national focal points which in turn link to national grids.

Discussion

Prof. Obiekezie: Most government facilities were not able to produce fish seed in the first place because they could not manage their broodstock. How come you want to turn over to them the management of the broodstock?

Dr. Moehl: My initial approach to the question is that in the first instance, the real problem of seed production and distribution with government facilities is that of distribution. The distribution costs are very high and transporting fingerlings in good condition to farmers is a very expensive venture especially with a very small number of hatcheries in a large distribution area. So in part, for the government facilities to meet the demand of farmers is a distribution problem. In many cases, the budgets are so small and unable to meet the large number of hatcheries available so that it is difficult to do anything of quality in any one place.

Some countries have many hatcheries with a very small budget which is distributed among these hatcheries so it is impossible to give quality attention to all these hatcheries.

The first step is for governments to disengage themselves from 30% of hatcheries within a five-year period and focus on centers that are designated as broodstock management centers. This, we hope, would lead to a significant reduction in the overall number of facilities that governments would maintain.

Prof. Ayinla: I do agree with John that the issue of broodstock be the responsibility of governmental research bodies and universities rather than compete with fish farmers in the production of seed. What are the research inputs necessary for development of Acadja systems in West Africa?

Dr. Moehl: Instead of addressing the Acadja system per se, I would like to use this opportunity to recommend as Patrick suggested in his presentation, the use of regional bodies for their maximum use. Research priorities need to be set and established by those in the region through whatever mechanism that is available and use organizations like WorldFish, CIFA etc. to assist in bringing together experts to pursue these research priorities and work together to pool resources and exchange information. This will lead to efficient use of the funds available and provide researchers with opportunities to collaborate widely across the region.

Dr. Rezk: Your point about making sure that farmers are getting the appropriate quality seed is greatly dependent upon who will be providing what to whom. Can you please elaborate upon what you mean?

Dr. Moehl: In my vision, I will propose two strategies: (i) that small-scale rural farmers produce their own seed which is already a common occurrence; and (ii) specialized private hatcheries would sell seed to a certain number of customers or clients. It is these two systems that we see as a means to provide seed to the majority of farmers.

Session IV: General Discussion and Conclusions

The discussion centered on the identification of research priorities and opportunities for pursuing them. The outputs of the session are classified into two broad areas: the identification of research priorities for the sub-region and elaborating specific means and opportunities for pursuing those research goals.

Research Priorities

1. Continue to conduct basic genetic studies in order to attain a fuller understanding of the range of fish genetic diversity available in the sub-region;

2. Alongside purely genetic investigations using currently available tools, morphological studies should be pursued to complement data from genetic research;

3. Biodiversity studies - both genetic and morphological - should result in clear categorization of fish species along the lines of the levels of threat to which they are exposed;

4. Research should be intensified into the Acadja system and other culture practices which enhance production such as pen culture and the Whedo systems. With regards to the Acadja system, the attendant problems of deforestation, eutrophication and socio-cultural/socio-economic issues should receive increased attention;

5. Research should be encouraged and intensified to develop techniques for mass-producing good quality fish seed on a reliable basis.

Opportunities for Pursuing Research Priorities

1. Training, institutional strengthening, capacity building:

- Provide access to specialized and well-equipped laboratories in West Africa for trainees on the whole range of genetic research.

- Such laboratories should be networked for more effective and rational use of resources and expertise.

- Encourage South-South cooperation in research. Specifically, liaison to be established with relevant laboratories in other parts of Africa - North, South, East and West.

- Encourage intersectoral partnerships with existing laboratories outside of the fisheries and aquaculture sector. Capabilities in the agriculture, livestock and forestry sectors should be evaluated and utilized as well as those of international organizations such as WorldFish, IITA, WARDA, ILRI, and ICRAF.

2. Generate and update databases on professionals and expertise within the sub-region as a means of promoting the desired networking.

3. Develop research programs which address regional and transboundary problems.

Session V

West African Fish and Fisheries Association (WAFA) Session

Chair: Dr. Anis Diallo

West African Fish and Fisheries Association (WAFA)

Philippe A. Lalèyè
Laboratoire d'Hydrobiologie et d'Aquaculture,
Faculté des Sciences Agronomiques de l'Université d'Abomey Calavi,
01 B.P. 526 Cotonou, Bénin

Following many years of attempts to establish an organization which would serve as a forum and platform for interaction and more collaborative fish and fisheries activities, the workshop on Fish Biodiversity Conservation in West African Wetlands organized by Wetlands International in October 1999 was taken as an opportunity by West Africans attending the meeting to launch the association, "West African Fish and Fisheries Association" (WAFA).

Arising from the Dakar meeting, one of the priority actions to be accomplished within the short term is to organize a general meeting during which the members would concretize their commitments to the association. This would provide a real base for the association and for the planning of the program of action for the next 3 to 5 years. The present meeting was initially scheduled for Ghana in 2000 but could not be realized due to the lack of funds. This meeting gives us the opportunity.

At this point we would like to thank the organizers of this workshop who made it possible for the different country representatives to attend and continue the discussion about WAFA. The aim of this presentation is to provide information to the participants of this meeting on the objectives, structure and the different actions in which WAFA would like to be involved. This would constitute the platform for discussion on the identification of prospects for research cooperation in fisheries and aquaculture in West Africa. WAFA will function as a network for scientists, fisheries and aquaculture practitioners in the West African sub-region.

West African Fish and Fisheries Association (WAFA)

The association was formed because there exists a need for a more systematic form of collaboration to exchange information and experience, assist in different types of training needed by members and allow for the formation of regional and sub-regional projects in the West Africa.

The objectives are:

- To promote interaction among fish and fisheries specialists in various fields related to the resources;
- To facilitate sub-regional coordinated activities in research, conservation and wise use of fish and fisheries resources;
- To assist in individual country or institutional activities whenever possible;
- To facilitate training of the members through sharing of facilities and human resources;
- To maintain an updated database on specialists, and a bibliography on indigenous knowledge, tools and techniques in the sub-region for members' use;
- To promote the awareness of local communities in relation to the status of wetlands and their resources in the sub-region and the need for their national use;
- To establish an international periodical to facilitate the publication of sub-regional relevant material.

WAFA Structure

WAFA is administered by a Central Executive Committee composed of a sub-regional coordinator and national coordinators.

Dr Philippe Lalèyè (Benin) has been proposed as the sub-regional coordinator with the following tasks:

- Coordinate all the activities of the Network;
- Run the secretariat of the Network;
- Produce an annual report on the status of the Network based on the bi-annual reports of the National Coordinators;
- Represent the Network at different fora when necessary;
- Seek funding and partners for the promotion of the Network;
- Maintain permanent contact with all the national coordinators;
- Ensure that the objectives of the Network are realized at the different national level; and
- Manage the finances of the Network.

The role of the national coordinators on the other hand include:

- Coordinate all the activities of the Network at the national level;
- Run the secretariat of the Network at the national level;
- Produce a bi-annual report on the activities of WAFA in the different countries;
- Represent the Network at different fora when necessary;
- Seek funding and partners for the promotion of the Network at the national level;
- Manage the finances of the Network at the national level; and
- Update information related to WAFA at the national level.

The names of the National Coordinators are presented below:

Countries	National coordinators
Benin	Prof Nestor Sakiti
Burkina Faso	Prof Gustave Kabre
Cameroon	Dr Pius Oben
Centrafrique	Dr N'Dodet Boniface
Côte d'Ivoire	Prof N'Douba Valentin
Gambia	Mrs Anna Cham
Ghana	Dr Entsua-Mensah Mamaa
Guinee	Dr Mody Hady Diallo
Mali	Dr Tiéma Niare
Mauritanie	Mr Diew Daha
Niger	Mr Harouna Ali
Nigeria	Prof Obiekezie Austin
Senegal	Dr Anis Diallo
Tchad	Mr Anza Zakara
Togo	Mr Moumouni Abdou Kérim

continue

Dr. Abban made significant contributions toward the establishment of the Association.

Program of Actions

- Legalize the existence of WAFA in each country;
- Develop a Newsletter for WAFA in order to disseminate information easily among the members and other interested parties;
- Develop a Scientific Journal on fish and fisheries in the West African region;
- Promote training activities for the members on different aspects of fish and fisheries research;
- Identify research needs for the West Africa region;
- Develop regional research-development projects on different aspects of fish and fisheries;
- Stimulate cooperation and exchange among different institutions concerned with fish and fisheries,
- Build up the knowledge accumulated and exchange experience on fish and fisheries in West Africa by having biannual scientific meetings.

Since 1999, a continuous promotion of the WAFA ensued. At the present time about 200 people from 17 countries are registered members. WAFA has also participated in the conception and development of an action plan for the conservation of fish biodiversity in West African Wetlands. The foreword of the document has been written by WAFA. WAFA has also participated in different scientific meetings at the sub-regional level to discuss problems concerning conservation of fish biodiversity. At present discussions on the project proposals that would cover and involve scientists and participants from the sub-region are on-going.

Discussion

Dr. Abban: Funding will be a problem for this Association. The Association should have research topics that would attract support.

Prof. Ayinla: A membership drive should be the next step. The National Coordinators should link up with the

National Association of Fisheries in each country so there would be no conflict of interest. In this way they would also have more contacts and more members.

Prof. Obiekezie: The objectives of WAFA should address the need for networking and collaboration across the sub-region. This need has been identified during the workshop.

Dr. Laleye: Each national coordinator has been asked to update the membership list and send it to the sub-regional coordinator. The statutes are being prepared.

Dr. Dugan: WAFA should learn from the experience of the Species Survival Commission of the IUCN and other scientific networks and associations. All Networks and associations such as WAFA will have a greater chance of success if there is a clear focus for the formation of the Association. The Association should put together a proposal to address a number of issues and programs. Do not make it too bureaucratic.

Dr. Entsua-Mensah: The need to have research topics centered on the rivers in West Africa and their watershed has been raised in a lot of our deliberations. In that way, transboundary problems can be addressed and expertise within the various countries will be tapped.

Dr. Pullin: There are some problem areas in fisheries statistics such as the adequacy of the data. WAFA could have a grapevine where members could help to collect proper data and verify the information sent out to FAO and other organizations. The Association should advertize in a page or two on someone else's newsletter. Examples of such newsletters are Info Peche, NAGA, and other organizations with existing websites. With regards to donors, WAFA can contact FAO, CTA, IDRC and WorldFish.

Dr. Dugan: Once again, WAFA should have a clear focus and priorities to be able to source funding. WorldFish is redeveloping its programs for Africa and West Asia. There may be a possibility of some funding if WAFA can contribute to some of its activities and identify issues.

Prospects

The issues and recommendations that have been raised in the meeting are the drafting of the WAFA statues or the documentation making WAFA a legal entity.

A newsletter is being proposed for dissemination to members as well as to the different national fisheries associations. This would not only inform members of WAFA news items but also serve to boost up its membership.

WAFA should also focus on developing proposals focusing on particular problems of the region in order to obtain funding for these priority projects.

One of the suggestions was for WAFA to address the problem of fisheries statistics in the sub-region.

It has also been suggested that WAFA advertize in other fisheries newsletters and websites (Info Peche, NAGA, etc.) to inform the fisheries and aquaculture community of their existence.

Summary of Sessions and Discussions

Session I - Biodiversity, Culture and Importance of Tilapias in West Africa

Objective: Common understanding of the issues.

Discussion/outputs: Distillation of key points and concerns.

A whole range of genetic tools are available for the study of fish biodiversity in West Africa. There is a need, however, to identify precisely what specific tools are relevant to meet specific objectives. Dr. Agnese's paper elucidated on various genetic tools for assessing fish biodiversity and culture practices. The tools include those applicable to living specimens (karyotypes and allozymes) as well as those which can be applied to preserved specimens (RFLP, RAPD, AFLP, microsatellite sequences). Both advantages and disadvantages of the different tools were discussed. It is, however, clear that not much work has been done on tropical fish species for the application of these tools. This, therefore, calls for collaboration and meaningful partnerships between countries in the region on one hand and the donor agencies on the other. The emphasis of partnerships and collaboration should emphasize human resource capacity building and strengthening of established laboratories in the region.

Dr. Abban's paper talked about the diversity of river systems and the range of importance of tilapia in the presence of this diversity. He, however, stressed that *O. niloticus* is the most important species in the region. The application of ecological models to the issue of importance of tilapia will be very significant in the future. The overview of the importance of tilapias in West Africa shows the need for more detailed analysis on various issues/questions such as:

- To what extent is the picture presented true of all countries or systems in West Africa?
- What is the extent of variation among/within species in West Africa?
- What is the impact on species of changing environmental factors; are we able to think forward to, say 5 – 10 years from now to see the threats to fish biodiversity, especially tilapias, and then do research based on these in order to give better information to enhance sustainable management, utilization and conservation of tilapias (fish biodiversity)?

Session II - The Project

Objective: Achievements, constraints and contributions to resource utilization and implications for future research, conservation and management of tilapias.

Discussion/outputs:
1. Identify future requirements to conserve this diversity and maximize its potential for future use.
2. Identify the problems and opportunities that need to be addressed if we are to determine and achieve the full value of *S. melanotheron* in the region.

Achievements, constraints and contributions to resource utilization for future research, conservation and management of tilapias

The first paper dealt with the taxonomy of *S. melanotheron* and the delineation of priority conservation area of the highest genetic diversity. This is a model to study biodiversity management. The second paper showcased the important laws, institutional mechanisms and environmental changes and their impacts in Egypt as well as the needs of tilapia aquaculture. The paper from South Africa reported on the resurgence of interest in highly profitable catfish culture as well as the lack of effective controls of alien species. It also touched on the impacts of *O. niloticus*. The paper presented by Mr. Adyakwa compared the early life history performance of Ghanaian *S. melanotheron* populations. Insignificant differences were reported but there are indications of different performance in different systems (e.g. pond environment seems best). It will be useful to compare growth curves obtained in the study with published data which are present in FishBase. The paper presented by Mr. Attipoe compared the growth performance of different *O. niloticus* populations from Lake Volta; some differences were observed but it is not clear what to do next. Is a complete diallele cross experiment justified? The last paper presented in the session reported on the performance of *S. melanotheron* in cage culture in Lake Ayeme. Mr. Ouattara observed attractive growth rates for this species in this freshwater environment.

Future requirements to conserve African fish biodiversity and maximize its potential for future use

- Use different management approaches – regional and national. Regional is preferable;
- Culture species in environments that are close to their natural environments;
- Promote sustainable aquaculture;
- Focus conservation efforts on centers of highest genetic diversity.

Problems and opportunities for aquaculture of ***S. melanotheron***

- There are indications of good performance in freshwater of *S. melanotheron*. It is highly recommended that aquaculture trials in this environment be pursued;
- The high performance Ivoirian strain (origin Senegal) is kept at the University of Montpellier following closure of the Ivoirian farm. This may be used as a source for future strain development;
- There is a need to research markets for small and large fish so as to design culture systems to supply both types of demand;
- There is a need to share results on *S. melanotheron* culture trials regionwide;
- There is a need to develop better *S. melanotheron* strains for brackish and freshwater culture, subject to biosafety.

Session III – Fish and Fisheries Resources: Utilization and Conservation

Objective: Identify future priorities for research and conservation.

Discussion/Outputs: Clear recommendations on priorities for future research and conservation of aquatic genetic resources in West Africa: specific recommendations on conservation of tilapias.

Recommendations of West African Tilapia genetic resources priorities for future research

Future research priorities:

- Monitor fish biodiversity in West Africa;
- Conduct broad-scale genetic studies on West Africa fish species and identify centers of genetic diversity;
- Use these data to elaborate conservation and management strategies;
- Increase research on the socio-economic and socio-ecological aspects of conservation;
- Survey the current status of introduced alien species and implications for future introductions;
- Analyze the impact of physical barriers and water management structures (connections and reservoirs) on movements of marine and freshwater fishes;
- Increase the production and quality of fish (seed);
- Assess markets;
- Increase the quality, availability and linkages of information (networking);
- Improve and study populations adapted to local conditions instead of blindly using exotic populations/strains and introducing them to "new" environments;
- Research on the genetic basis of important traits (growth, set, salinity tolerance) for aquaculture;
- Extend genetic studies from cultured fish to wild stocks with which they might interact;

- Develop fish feed for aquaculture locally and using local resources;
- Determine the reaction of the fish to (climatic) variation;
- Revise legislation.

Recommendations for Conservation:

- Preserve biodiversity (ecosystems, species, genomic);
- Limit introductions of exotic gene pools (GMOs, hybrids, strains, subspecies, species).

General suggestions for management (sustainable utilization and conservation):

- Research into aquaculture expansion, and on conservation of both farmed and wild genetic resources, should both proceed with adequate funding;
- Improve the knowledge on biology (ecology, physiology, behavior, morphology, parasitology, disease resistance, etc.) at local level;
- Develop resource management policies involving West African coastal stakeholders based on common property philosophy;
- Preserve/protect sensitive habitats (e.g. mangroves) on a regional basis and harmonize legislation.

Session IV - International Perspectives

Objectives: Identify opportunities for pursuing the agreed research priorities through linkage with relevant institutions and programs.

Discussion/outputs: Specific opportunities for pursuing agreed priorities identified.

The discussion centered on the identification of research priorities and opportunities for pursuing them. The outputs of the session are classified into two broad areas: the identification of research priorities for the sub-region and elaborating specific means and opportunities for pursuing these research goals.

Research Priorities

- Continue to conduct basic genetic studies in order to attain a fuller understanding of the range of fish genetic diversity available in the sub-region;
- Alongside purely genetic investigations using currently available tools, morphological studies should be pursued to complement data from genetic research;
- Biodiversity studies - both genetic and morphological - should result in clear categorization of fish species according to threats to which they are exposed;
- Research should be intensified into the Acadja system and other culture practices which enhance production such as pen culture and the Whedo systems. With regards to the Acadja system, the attendant problems of deforestation, eutrophication and socio-cultural/socio-economic issues should receive increased attention;
- Research should be encouraged and intensified to develop techniques for mass-producing good quality fish seed on a reliable basis.

Opportunities for pursuing research priorities

- Training, Institutional strengthening and Capacity building.
    1. Provide access to specialized and well-equipped laboratories for trainees in the whole range of genetic research.
    2. Such laboratories should be networked for more effective and rational use of resources and expertise.
    3. Encourage South-South cooperation in research. Specifically, liaison should be established with relevant laboratories in other parts of Africa - North, South, East and West.

4. Encourage intersectoral partnerships with existing laboratories outside of the fisheries and aquaculture sector. Capabilities in the agriculture, livestock and forestry sectors should be evaluated and utilized as well as those of international organizations (WorldFish, IITA, WARDA, ILRI, and ICRAF).

- Generate and update databases on professionals and expertise within the sub-region as a means of promoting the desired networking.

- Develop research programs which address regional/ transboundary problems.

Session V - WAFA

Objectives: Identify prospects for research cooperation in fisheries and aquaculture in West Africa.

Discussion

Dr. Philippe Lal**è**y**è**, sub-regional of WAFA opened the session with an overview of the historic aims and objectives of the West African Fish and Fisheries Association. He elaborated on the role of the Sub-Regional Co-coordinator, the National Coordinators and gave the program of Action for WAFA and what had been done since the inauguration of the Association in Senegal in 1999.

The issues and recommendations that have been raised in the meeting are:

- In drafting the WAFA statues or the documentation making WAFA a legal entity, the objectives of WAFA should address the need for networking and collaboration across the sub-region. This need has been identified during the workshop;
- WAFA should have a clear focus and priorities to be able to source funding. WorldFish is redeveloping its programs for Africa and West Asia. There may be possibility of some funding if WAFA can contribute to some of the activities and issues identified. WAFA should learn from the experience of the Species Survival Commission of the IUCN and other scientific networks and associations. All networks and associations such as WAFA will have a greater chance of success if there is a clear focus for the formation of the Association. The Association should put together a proposal to address a number of issues and programs, with regards to donors, WAFA can contact FAO, CTA, IDRC and WorldFish, for assistance;
- A newsletter is being proposed for dissemination to members as well as to the different national fisheries associations. This would not only inform members of WAFA news items but also serve to boost up its membership;
- WAFA should also focus on developing proposals focusing on particular problems of the region in order to obtain funding for these priority projects (some of them are listed below);
- One of the suggestions was for WAFA to address the problem of fisheries statistics in the sub-region. There are some problem areas in fisheries statistics such as the adequacy of the data. WAFA could have a grapevine where members could help to collect proper data and verify the information sent out to FAO and other organizations;
- The need to have research topics centered on the river bodies in West Africa and their watershed has been raised in a lot of our deliberations. In that way, transboundary problems can be addressed and expertise within the various countries will be tapped;
- The Association should advertise in other newsletters, and on other organizations' web sites, to inform the fisheries and aquaculture community of their existence. Examples of such newsletters are Info Peche and NAGA.

Appendices

List of Participants

Bénin

Chikou, Mr. Antoine (WAFA)
FSA/UAC, 01 BP 526 Cotonou, Bénin
Ph: (00229) 303688
Email: achiku@avu.org

Lalèyè, Dr. Philippe (WAFA)
Université d'Abomey Calavi
Faculté des Sciences Agronomiques
01 BP 526 Cotonou, Bénin
Ph: (229) 36 01 26/30 36 88
Fax: (229) 36 01 22/ 30 30 84
Email: phlaleye@firstnet1.com

Sakiti, Mr. Nestor G. (WAFA)
Universite d'Abomey-Calavi
BP 526 Cotonou, Bénin
Ph: (229) 360074, Post 332 or
(229) 360126/303688
Fax: (229) 35 06 32
Email: sakiti@syfed.bj.refer.org

Burkina Faso

Kabre, Prof. Gustave (WAFA)
Laboratoire de Biologie Animale
UFR-SVT, Universite de Ouagadougou
03 BP 7021 Ouagadougou 03, Burkina Faso
Ph: (226) 332041/308852/363038
Fax: (226) 307242
Email: gkabre@fast.univ-ouaga.bf;
gkabre@univ-ouaga.bf

Côte d'Ivoire

Ouattara, Mr. Issa Nahoua
Université de Cocody
UFR- Biosciences, Laboratoire d'Hydrobiologie
22 BP 582, Abidjan 22, Côte d'Ivoire
Email: pisciaboisso@avisco.ci

France

Agnèse, Dr. Jean-Francois
IRD CNRS Laboratoire Génome Populations Intéractions
UMR5000, CC 63, Univ. Montpellier II
34 000 Montpellier, France
Email: agnese@mpl.ird.fr;
agnese@crit.univ-montp2.fr

Bezault, Mr. Etienne
UR Aquaculture - CIRAD-EMVT &
Laboratory of Fish Genetics - INRA
Avenue Agropolis TA 30/01
34 398 Montpellier Cedex 5, France
Ph: 33 (0)4 67 04 33 91
Fax: 33 (0)4 67 63 57 95
Email: bezault@cirad.fr

Fermon, Dr. Yves
Laboratoire d'Ichtyologie Générale et Appliquée
Museum National d'Histoire Naturelle
43, rue Cuvier, 75231 Paris Cedex 05, France
Ph: 33 1 40 79 37 34
Fax: 33 1 40 79 37 71
Email: fermon@mnhn.fr;
yves.fermon@wanadoo.fr

Germany

Falk, Dr. Thomas
Zoologisches Institut und Zoologisches Museum
Universitat Hamburg, Martin-Luther-King-Platz-3
20146 Hamburg, Germany
Ph: (49-40) 42838-3926
Fax: (49-40) 42838-3937
Email: thomas.falk@uni-hamburg.de

Ghana

Abban, Dr. Eddie Kofi
Water Research Institute
Council for Scientific and Industrial Research
P.O. Box 38, Achimota, Ghana
Ph: (233-21) 768310
Fax: (233-21) 777170
Email: eap@africaonline.com.gh

Agbleze, Mr. Mayor
Youfardes/SaveFish Project
P.O. Box AK 569, Darkuman, Accra, Ghana
Ph: 233 21 404471/223197

Fax: 233 21 223258
Email: agblezemayor@hotmail.com

Agyakwa, Mr. Seth
Water Research Institute
Council for Scientific and Industrial Research
P.O. Box 38, Achimota, Ghana
Ph: (233-21) 775135, 775511, 779514/5
Fax: (233-21) 777170
Email: aktorinmade@yahoo.com; wri@ghana.com

Attipoe, Mr. Felix
Water Research Institute
Council for Scientific and Industrial Research
P.O. Box 38, Achimota, Ghana
Ph: (233-21) 775135, 775511 and 779514/5
Fax: (233-21) 777170
Email: fattipoe@hotmail.com; wri@ghana.com

Biney, Dr. Charles A.
Director
Water Research Institute
Council for Scientific and Industrial Research
P. O. Box M.32, Accra, Ghana
Email: wri@ghana.com

Dankwa, Dr. Hederick R.
Water Research Institute
Council for Scientific and Industrial Research
P.O. Box 38, Achimota, Ghana
Ph: (233-21) 775135, 779514, 779515
Fax: (233-21) 777170, 761030
Email: wri@ghana.com

Entsua-Mensah, Dr. Mamaa (WAFA)
Water Research Institute
Council for Scientific and Industrial Research
P.O. Box 38, Achimota, Ghana
Ph: (233-21) 775511, 761031
Fax: (233-21) 761030, 777170
Email: mamaa@libr.ug.edu.gh; mamaa@yahoo.com

Kwarfo-Apegyah, Mr. K.
Water Research Institute
Council for Scientific and Industrial Research
Box 695 Tamale, Ghana
Ph: 233 071 23448/9
Email: kwarfoapegyah@yahoo.com

Quarcoopome, Mr. Theodore
Water Research Institute
Council for Scientific and Industrial Research
P.O. Box 38, Achimota, Ghana
Ph: (233-21)-779514/5
Fax: (233-21)-761030/777170
Email: gpome@yahoo.com

Guinea

Diallo, Dr. Mody Hady (WAFA)
Chef de la Division Peche Continentale et Pisciculture
Conakry Rep. Guinea, BP: 307
Tel: (224) 29 44 50/41 52 27
Email: dmhady@afribone.net.gn

Malawi

Changadeya, Mr. Wisdom
Laboratory Manager
Molecular Biology and Ecology Research Unit (MBERU), AMBAKA Building
Chancellor College Campus, Box 403
Zomba, Malawi
Ph: 265-525-695/265-877-858
Fax: 265-525-829
Email: wchanga@chanco.unima.mw

Niger

Harouna, Mr. Ali (WAFA)
Direction Faune-Pêche-Pisciculture
B.P. 721, Niamey, Niger
Ph: 227 73 40 69/ 73 33 29
Ph/Fax: 227 73 60 12
Email: ftppount@intnet.ne; faune@intnet.ne

Nigeria

Adeogun, Ms. Iyabo
Dept. of Animal Science
Obefemi Awolowo University
Ile-Ife, Nigeria
Email: iadeogun@oauife.edu.ng

Awodiran, Mr. M. O.
Dept. of Zoology
Obefemi Awolowo University
Ile-Ife, Nigeria
Email: midifemi@yahoo.com; sogbogu@oauife.edu.ng

Ayinla, Dr. O. A.
Asst. Director
Nigerian Institute of Oceanography and Marine Research
Federal Ministry of Agriculture
P. M. B. 12729, Victoria Island, Lagos, Nigeria
Ph: 234-01 261 7530
Fax: 234-01 261 7530
Email: niomr@linkserve.com.ng

Fagbenro, Prof. Oyedapo (WAFA)
Department of Fisheries and Wildlife
Federal University of Technology
PMB 704 Akure
Ondo State, Nigeria
Ph: 234-034-243744
Email: fagbenro_dapo@yahoo.com

Obiekezie, Prof. Austin (WAFA)
Institute of Oceonography and Fisheries
P. M. B. 1115, Calabar, Nigeria
Email: obiekezieai@yahoo.com

Olaleye, Dr. Victor
Dept. of Zoology
Obefemi Awolowo University
Ile-Ife, Nigeria
Email: volaleye@oauife.edu.ng;
foluwaola@hotmail.com

Taiwo, Mrs. Yetunde F.
Museum of Natural History
Obefemi Awolowo University
Ile-Ife, Nigeria
Email: yftaiwo2@yahoo.co.uk

Philippines

Pullin, Dr. Roger
7A Legaspi Park View
134 Legaspi Street
Makati City 1229
Metro Manila, Philippines
Ph: 63 (2) 818-0870
Fax: 63 (2) 840-2630
Email: karoger@pacific.net.ph

Senegal

Diallo, Dr. Anis (WAFA)
Centre de Recherches Océanolographiques de Dakar-Thiaroye
BP 2241
Dakar, Sénégal
Fax: (221) 8340536/8342792
Email: adiallo@crodt.isra.sn;
anis_diallo@hotmail.com;
a.diallo@odinafrica.net

South Africa

Van der Bank, Dr. Herman
Department of Zoology
Rand Africaans University
PO Box 524, Auckland Park 2006
South Africa
Ph: 27 11 489 2450
Fax: 29 11 489 2286
Email: FHVDB@na.rau.ac.za

FAO - Ghana

Moehl, Dr. John
Regional Aquaculture Officer, RAFI
FAO Regional Office for Africa
Gamel Abdul Nasser Road
P. O. Box 1628, Accra, Ghana
Ph: 233-21-701-0930 Ext. 3161
233-21-675-000 Ext. 3161 or 3206
Fax: 233-21-701-0943, 233-21-668-427
Email: john.moehl@fao.org

French Embassy – Ghana

Decraene, Mr. Denis
Cooperation Attache
Agriculture, Research, Environment and Audiovisual
Ambassade de France
P.O. Box 187
Accra, Ghana
Ph: 233 21 774469/228504
Fax: 233 21 773488
Email: denis.decraene@diplomatie.gouv.fr

WorldFish - Egypt

Dugan, Dr. Patrick
WorldFish Center - Regional Center for Africa and West Asia
P.O. Box 1261, Maadi, Cairo, Egypt
Ph: 20(55) 340 4226
Fax: 20(55) 340 5578
Email: p.dugan@cgiar.org

Rezk, Dr. Mahmoud
WorldFish Center - Regional Center for Africa and West Asia
P. O. Box 1261, Maadi, Cairo, Egypt
Ph: 20(55) 340 4226
Fax: 20(55) 340 5578
Email: m.rezk@cgiar.org

WorldFish - Philippines

Casal, Ms. Christine Marie
WorldFish Center - Philippines Office
IRRI, Los Baños
Philippines
Ph: (63-2) 812-8641
Fax: (63-2) 816-3183
Email: c.casal@cgiar.org

Acronyms

ADCP/REP	Aquaculture Development and Coordination Programme
AF	Average fecundity
AFD	Agence Française de Dévelopment
AFLP	Amplified Fragment Length Polymorphisms
ANOVA	Analysis of Variance
BMZ	Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung
CBD	Convention on Biological Diversity
CIFA	Committee for Inland Fisheries of Africa
CIRAD-EMVT	Centre de coopération internationale en recherche agronomique pour le développement - Elevage et médecine vétérinaire
CSIR	Council for Scientific and Industrial Research
CTA	Centre Technique de Coopération Agricole et Rural ACP-UE
FAO	Food and Agricultural Organization of the United Nations
GMO	Genetically Modified Organisms
GTZ	German Technical Cooperation/Abteilung Gesellschaft für Technische Zusammenarbeit
IAB	Institute of Aquatic Biology
ICLARM	International Center for Living Aquatic Resources Management
ICRAF	International Center for Research in Agroforestry (World Agroforestry Center)
IDRC	International Development Research Centre
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
INRA	National Institute for Agricultural Research (France)
IUCN	The World Conservation Union (International Union for Conservation of Nature and Natural Resources)
MRAC	Musée Royal de l'Afrique Centrale
NACA	Network of Aquaculture Centres in Asia-Pacific
NRF	National Research Foundation
ORSTOM	Institut Français de Recherche Scientifique pour le développement en Coopération
PCR	Polymerase Chain Reaction
RAFI	Fisheries Department Group of the Regional Office for Africa
RAPD	Randomly Amplified Polymorphic DNA
RAU	Rand Africaans University
RFLP	Restriction Fragment Length Polymorphisms
UH	Univeristy of Hamburg
UNEP	United Nations Environment Prpogram
WAFA	West African Fisheries Association
WARDA	West Africa Rice Development Association
WRI	Water Research Institute
WRRI	Water Resources Research Institute
ZIM	Zoologisches Institut und Museum