Edited by R.S.V. Pullin

INTERNATIONAL CENTER FOR LIVING AQUATIC
RESOURCES MANAGEMENT

ERRATUM

The last species in Table 9, p. 70
should be
Tilapia zillii, not *Tilapia rendalli*.

Tilapia Genetic Resources for Aquaculture

Proceedings of the Workshop on Tilapia Genetic Resources for Aquaculture
23-24 March 1987
Bangkok, Thailand

Edited by

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1988

ICLARM
INTERNATIONAL CENTER FOR LIVING AQUATIC RESOURCES MANAGEMENT
MANILA, PHILIPPINES

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Cover: Nile tilapia *(Oreochromis niloticus)*
at the Institut des Savanes, Bouaké,
Côte d'Ivoire (photo by R.S.V. Pullin)

ICLARM Contribution No. 457.

Contents

Preface

The tilapias are African fishes that are used in warmwater aquaculture throughout the world. Some species, such as the Nile tilapia (*Oreochromis niloticus*), are highly versatile, herbivorous - microphagous feeders, well-suited to low technology farming systems in third-world countries. Tilapia culture has made great advances in the last ten years in some Asian countries, including the Philippines, Thailand and China, but remains poorly developed in Africa and other regions.

This workshop was convened to focus on tilapia genetic resources and their future use in aquaculture. It arose from a growing realization by ICLARM and its collaborators that tilapia culture in Asian and other nonAfrican countries is presently based on a very narrow genetic base from a few small founder populations. By contrast, African countries, many of which urgently need assistance to develop their own aquaculture sectors, hold the global wealth of tilapia genetic resources. These resources have yet to be tapped to improve cultured tilapia breeds. Moreover, many wild tilapia populations in Africa are under threat of irreversible change or loss from factors such as fish and water transfers and habitat disturbance.

To discuss tilapia genetic resources for aquaculture, therefore, requires an approach combining ecology, genetics, culture technology and the politics and economics of conservation and development. Most of these topics were discussed in sessions of the Second International Symposium on Tilapia in Aquaculture (ISTA II), 16-20 March 1987 (Pullin et al., in press) which was also held in Bangkok just before this workshop.

The opportunity was taken to invite a small group of ISTA II participants (tilapia biologists, geneticists and culturists from Africa, Asia and other countries) to discuss the documentation, evaluation and utilization of tilapia genetic resources. In order to promote as much free discussion as possible, participants were asked to speak rather than to present lengthy papers.

The contributions and discussions included in this summary report have been transcribed from two days of tape-recordings. The workshop was limited to a small gathering of participants from selected countries and institutions collaborating with ICLARM in genetics research. Had it been expanded to include representatives from all countries and research institutions interested in tilapia culture and tilapia genetics, it would have become a large conference, not a small workshop conducive to discussions.

The workshop format worked well. The discussions on documentation, conservation, evaluation and use of tilapia genetic resources were lively and productive and resulted in clear recommendations for future action. Where will this lead? Hopefully to a new international program of action by those present and their colleagues.

The workshop was made possible by the generous sponsorship of the Bundesministerium für Wirtschaftliche Zusammenarbeit (BMZ) (The Ministry of Technical Cooperation of the Federal Republic of Germany) as part of a BMZ-funded program of Israeli-German-ICLARM Research Cooperation to Benefit Technical Cooperation with Third-World Countries. ICLARM and all the workshop participants greatly appreciate this generous and farsighted support. The participants from African nations were sponsored in part by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), GmbH, through its project support to ICLARM.

I believe that the workshop will probably be seen as a milestone along the path to genetic conservation and improvement of the world's most widely cultured warmwater fishes. I hope the readers will agree.

R.S.V. PULLIN
July 1988

The Current Status of Tilapia Genetic Resources for Aquaculture

Session I. Resource Papers on Tilapias in Africa

Chairperson: Dr. R.H. Lowe-McConnell

Opening Remarks

Dr. Lowe-McConnell welcomed everyone and introduced Dr. Pullin, the organizer of the workshop. Dr. Pullin then introduced the workshop participants and asked Dr. Lowe-McConnell to express the good wishes of all present to Dr. E. Trewavas (British Museum), who was unable to attend but had sent material for discussion.

Dr. Villwock then explained the aims and objectives of the meeting, beginning by acknowledging sponsorship of the meeting by the Bundesministerium für Wirtschaftliche Zusammenarbeit (BMZ) of the Government of the Federal Republic of Germany and the interest of BMZ and the German Agency for Technical Cooperation (GTZ), GmbH in tilapia genetics research for third-world aquaculture development. He further stated that the recommendations made by the workshop would provide a framework for future research in this important field.

Additional introductory remarks were given by Dr. Pullin who summarized the paper by Pullin and Capili (in press; Appendix I) as being a statement of ICLARM's views on the problems and prospects for genetic improvement of cultured tilapias, with particular reference to the tilapia genetic resources of Africa and Asia. The paper calls for future research on 1) documentation and 2) evaluation of tilapia genetic resources, followed by 3) the use of promising material in selective breeding schemes. This stepwise approach was stressed by Dr. Pullin. It was agreed that the meeting follow the same stepwise approach for its agenda of discussions.

Dr. Pullin referred to the reviews by Balarin and Hatton (1979), Lowe-McConnell (1982), Philippart and Ruwet (1982) and Trewavas (1982, 1983) and the bibliographies by Thys van den Audenaerde (1968) and Schoenen (1982, 1984, 1985) as the best sources of collected information on tilapias in Africa.

Natural Distribution of Tilapias and Its Consequences for the Possible Protection of Genetic Resources

Dr. D.F.E. Thys van den Audenaerde

Early fish culture attempts in Africa and attitudes to tilapia transfers

About forty years ago, tilapia culture using *Oreochromis macrochir* and *Tilapia rendalli* was started in what was then Upper Katanga, Belgian Congo (now Shaba). These fish reached market size after 8-10 months in pond culture and bred at all temperatures above 23°C. From 18-23°C they grew well but did not reproduce. During the breeding season (about 4 months per year) their growth suffered because of excessive reproduction. Lower temperatures during the cold, dry season also caused a growth check.

Tilapia were then moved from there to what is now central Zaïre, especially to the fishponds at Yangambi. The water temperature here is 25-26°C year-round and there was excessive reproduction by fish as small as 5-6 cm in length. This gave rise to a feeling at that time that a tilapia species should not be transferred for culture outside its natural range. This aroused interest in studying the *natural* distribution of tilapias throughout Africa.

There were some early transfers of tilapia. For example, there is a record of tilapia in southern Morocco in the 1920s. This could be assumed to be a natural occurrence, but the French Foreign Legion transported fish from one well to another in the 1920s and 1930s so that the distribution patterns for tilapias and *Barbus* spp. throughout the Sahara are confusing.

From 1945 onwards, there were many transfers and now the whole situation of tilapia distribution in Africa is confusing and disappointing from the point of view of conservation of natural genetic resources. There are, however, still some ecological barriers to the natural spread of some species. For example *T. sparrmanii* can live on the high plateaux and never descends to colonize rainforest waters, despite the absence of any physical barriers such as waterfalls.

The current situation; examples of different species groups

The substrate spawners

Tilapia zillii presents a relict type of distribution (Fig. 1). It was formerly much more widespread than now. The 'drying-up' of much of Africa has produced such relict patterns, especially in the highland areas. Its distribution extends into the rainforest and around Kisangani it meets the distribution area of *T. rendalli*. *T. rendalli* has been spread widely through Africa and beyond under the misnomer '*T. melanopleura*'. Another substrate spawner is *T. congica*, an equatorial rainforest species that prefers acidic waters (Fig. 2). *T. rendalli* and *T. congica* distributions have almost no overlap, even though the species are very closely related. They are

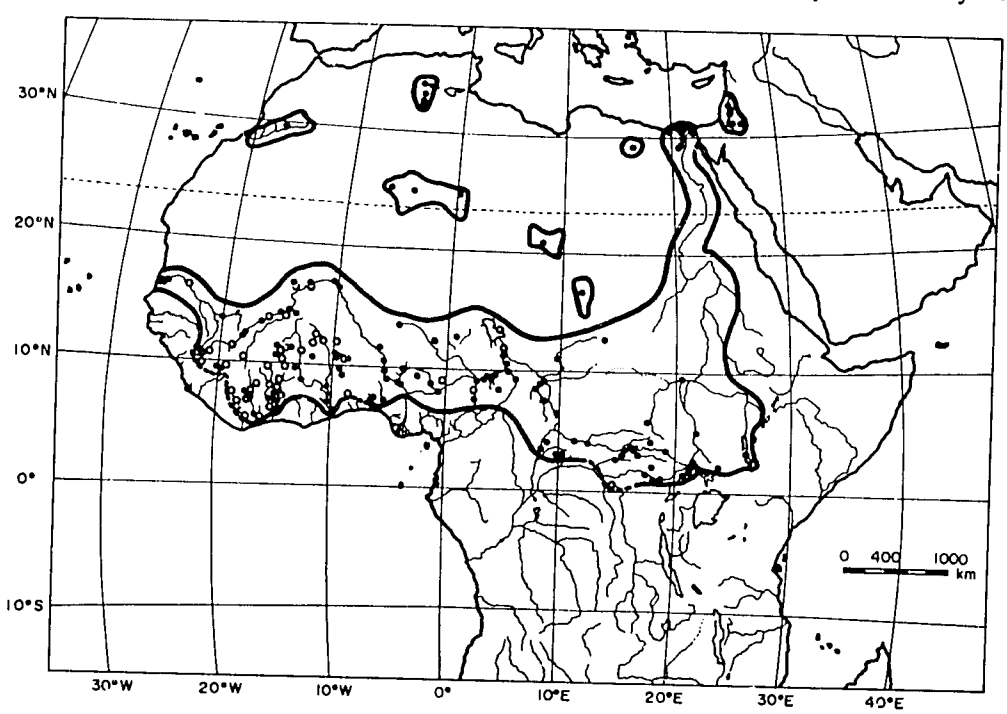

Fig. 1. Distribution of *Tilapia zillii*. Black dots indicate samples checked personally by the author; white dots indicate published records regarded as reliable.

generally considered to be herbivorous but can take many food items. *T. rendalli* is the most important of these species for aquaculture. *T. rendalli* is present in Lake Tanganyika but remains in the inshore zone and has not colonized the open waters of the lake. Its distribution is given in Fig. 3.

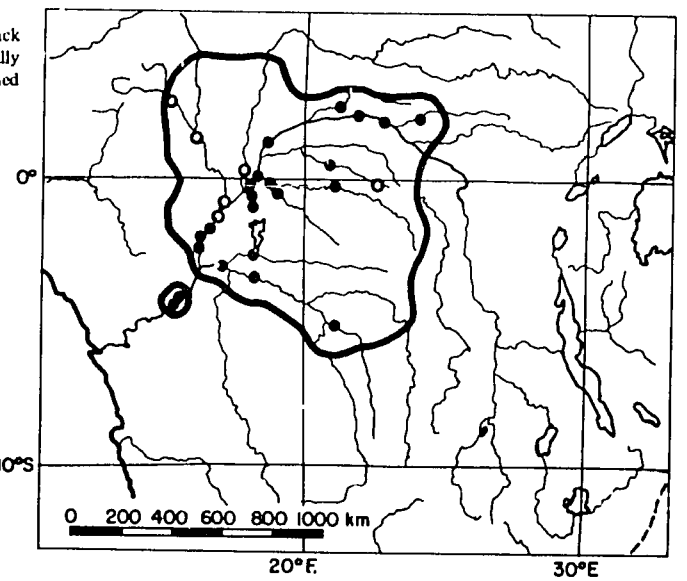

Fig. 2. Distribution of *Tilapia congica*. Black dots indicate samples checked personally by the author; white dots indicate published records regarded as reliable.

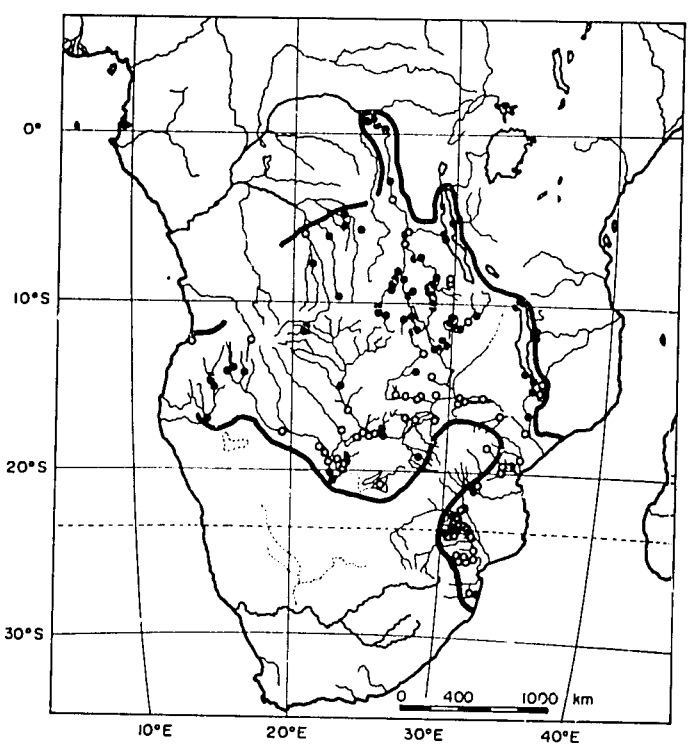

Fig. 3. Distribution of *Tilapia rendalli*. Black dots indicate samples checked personally by the author; white dots indicate published records regarded as reliable.

T. guineensis (Fig. 4) is a brackishwater substrate spawner that can even breed in seawater. It breeds in the Yacht Club at Dakar, Sénégal. In the northernmost west African river, Sénégal, *T. guineensis* persists in the estuaries but is replaced by *T. zillii* in fully freshwater. There are no *T. guineensis* beyond 150-200 km up river in the rainy season and none beyond 20-30 km from the coast in the dry season. There is little or no current in the dry season; the species are kept apart by competition. Further south in the Gambia and the Casamanse Rivers, *T. zillii* is absent. Here *T. guineensis* penetrates far inland up to the source of these rivers and so colonizes purely freshwater. [*T. guineensis* and *S. melanotheron* are found together in brackishwater in lagoons and in the Niger Delta in Nigeria, without *T. zillii* (M.M.J. Vincke, pers. comm. to Editor)].

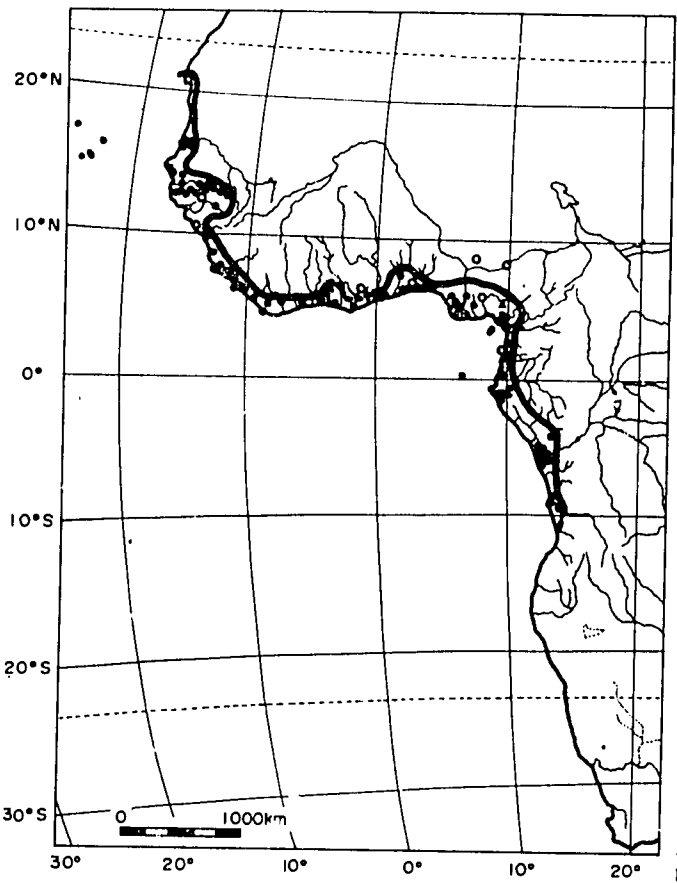

Fig. 4. Distribution of *Tilapia guineensis*. Black dots indicate samples checked personally by the author; white dots indicate published records regarded as reliable.

In Cameroun, there is the Ntem River (the border between southwest Cameroun and Gabon), where *T. guineensis* also extends far inland to the sources of the river. Here this normally brackishwater species inhabits fast flowing rapids and rainforest waters in fully freshwater.

The mouth brooders

Oreochromis macrochir inhabits the high plateaux of the savannah, south of the rainforest. It does not extend naturally further down into the Kariba system and southern Africa. In the north, there is a break in its distribution at the Upemba falls where it is replaced by *O. upembae* and the two species remain totally allopatric there. The extreme northeast of its distribution is the Luapula-Mweru system (two swampy lakes linked by the Luapula river): almost everything that

has been used under the name *O. macrochir* for fish culture has come from this area. In 1945, there was a transportation overnight (to avoid high daytime temperatures) of about 10 pairs of *O. macrochir* (large fish from the Luapula stream) to the former Elizabethville (now Lubumbashi), Zaïre. They were bred in ponds and then spread over all the former Belgian Congo, now Zaïre, and to Rwanda, Burundi, Congo Brazzaville, Côte d'Ivoire and Cameroun. They have also been found in remote areas in Togo and in a remote rainforest area in Liberia. The strain present is always the same: Luapula-Mweru - origin. This strain builds a very characteristic star-shaped nest. The Kafue River strain has a totally different nest. There may be other nest types associated with other strains but information on this is lacking.

The important point is that nearly all *O. macrochir* used for culture purposes in Africa have been derived from about 10 pairs of fish which themselves came from Luapula-Mweru and were not representative of the whole natural distribution of the species.

O. macrochir (Fig. 5) remains totally an inland species with no spread into coastal ecosystems. It has very low salinity tolerance. However, there are some salt springs in Upper Katanga (Shaba) in which a special population of *O. macrochir* survives - called *salinicola* (Fig. 6). This is a good example of a local 'strain' adapting to adverse conditions which the species normally avoids. It could be termed a separate species. The genetic plasticity of tilapias therefore cannot always be deduced from their natural distribution patterns.

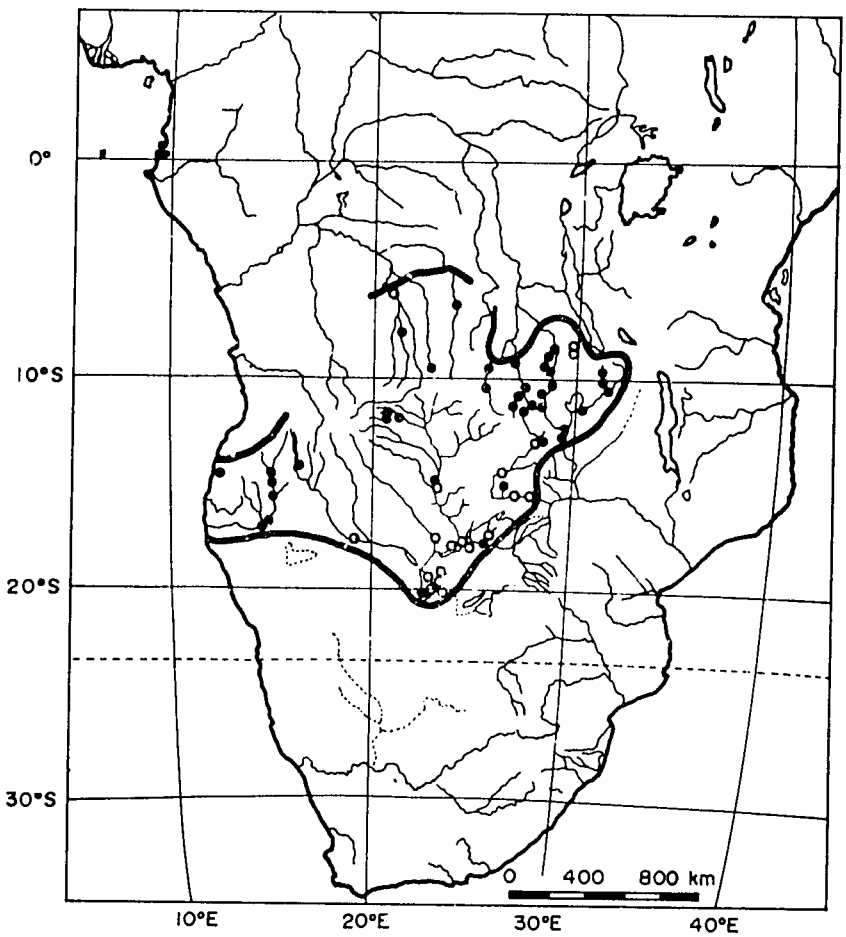

Fig. 5. Distribution of *Oreochromis macrochir*. Black dots indicate samples checked personally by the author; white dots indicate published records regarded as reliable.

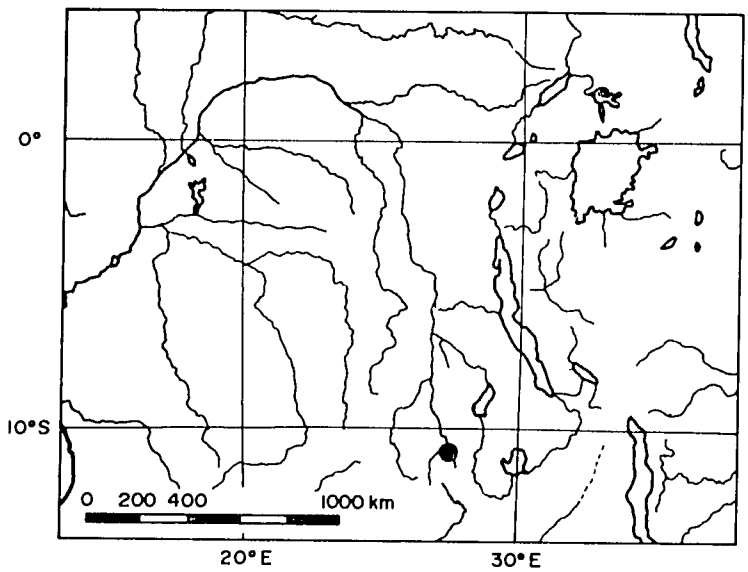

Fig. 6. Location of the population of *Oreochromis macrochir* (●) termed *'Tilapia salinicola'*.

The distribution of two closely related species - *O. mossambicus* and *O. mortimeri* (Fig. 7) - is limited by various factors: for example, mountains and falls to the west and the 5-7°C isotherm in the south. There is another closely related species, *O. ruvumae* in the Ruvuma River to the north. *O. mossambicus* survives almost anywhere in suitable temperatures and was the first species to persuade people to break the earlier rule that tilapia species should not be cultured outside their natural range. [It was a poor choice for many reasons, now well-documented. Moreau et al. (1986) have shown its growth performance in natural waters to be inferior to other species; see p. 72-73 - Editor].

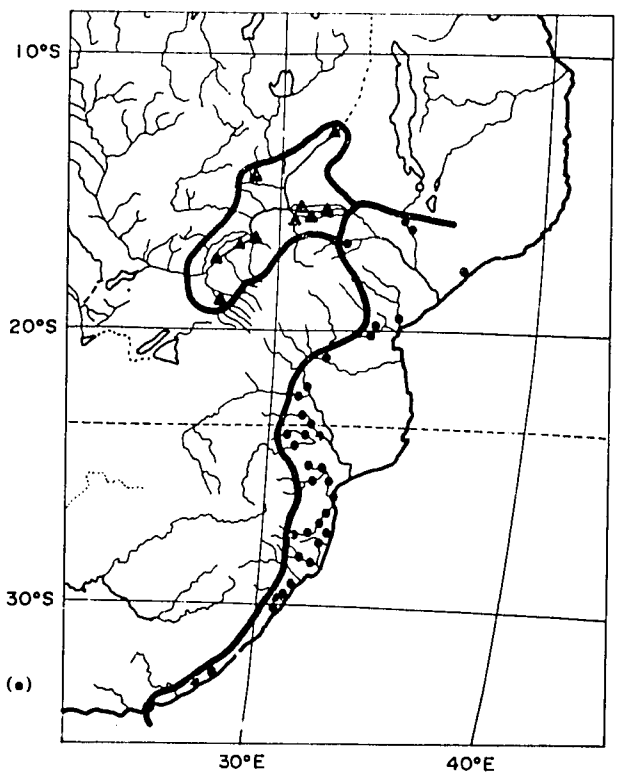

Fig. 7. Distribution of *Oreochromis mossambicus* (●) and *O. mortimeri* (▲).

Turning to other species such as *O. niloticus* (Fig. 8), which is very important in aquaculture, the first transfers of this species in Francophone Africa were made largely by a French organization, the Centre Technique Forestier Tropical (CTFT). These early transfers (1956-68) were all derived from a waterhole in Burkina Faso (formerly Upper Volta), close to Bobodioulasso, called 'la mare aux hippos' - the hippo waterhole. [La mare aux hippos is a name used for other waterbodies; for example, a portion of the bed of the Pendjari River, Bénin, i.e., not an isolated waterhole, but rather running water for part of the year (M.M.J. Vincke, pers. comm. to Editor)]. So, these early transfers derived from an isolated population beside a river system. The population may well have been stunted. This strain was sent to Bouaké, Côte d'Ivoire, and from there to many other places. [See p. 22-24 and 25-26 for further information on *O. niloticus* at Bouaké - Editor].

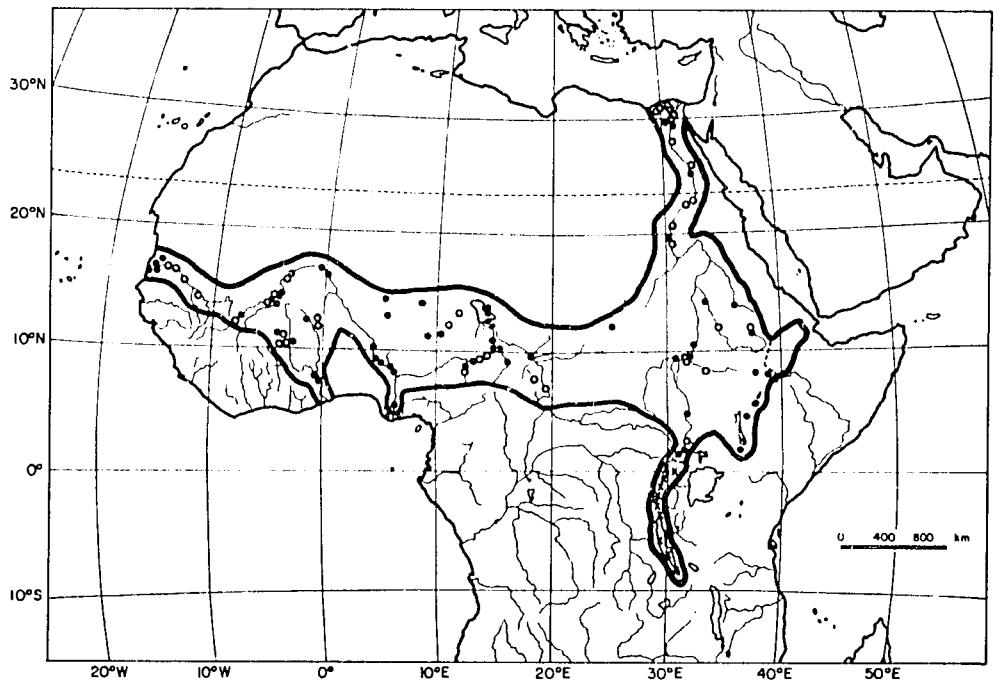

Fig. 8. Distribution of *Oreochromis niloticus niloticus:* black dots (•) indicate samples checked personally by the author, white dots (o) indicate published records regarded as reliable. Distribution of the subspecies *O.n. eduardianus* (x) is also shown. (cf. p. 15 and Appendices I and III – Editor).

In Madagascar, it was hybridized with *O. macrochir*. It was also spread from Bouaké, Côte d'Ivoire to Brazzaville and to Bangui, Central African Republic. *O. niloticus*, however, has a very wide natural distribution and must encompass many strains that have never been used for fish culture. *O. niloticus* in Cameroun was first tested for aquaculture in 1956 with a view to replacing *O. macrochir* (Bard 1960).

O. aureus has a rather strange, discontinuous distribution (Fig. 9), and here again there are probably many strains that have never been evaluated for fish culture; for example, the west African populations. Its natural distribution extends to Israel as does that of *Sarotherodon galilaeus*, which shows some relict distribution patterns (Fig. 10), especially in the Sahara. *S. galilaeus* inhabits the north of the Zaïre system but is totally absent from the central part of this system (which is very acidic and lacks any naturally occurring microphagous tilapias). However, in the Malebo pool, a natural lake on a savannah system beyond the Zaïre rainforest, there is a natural population of *S. galilaeus*, characterized by a rather low number of scales and a thick, scaly caudal fin. This is one of several examples of isolated populations that have reached savannah land pools from origins in rainforest river systems.

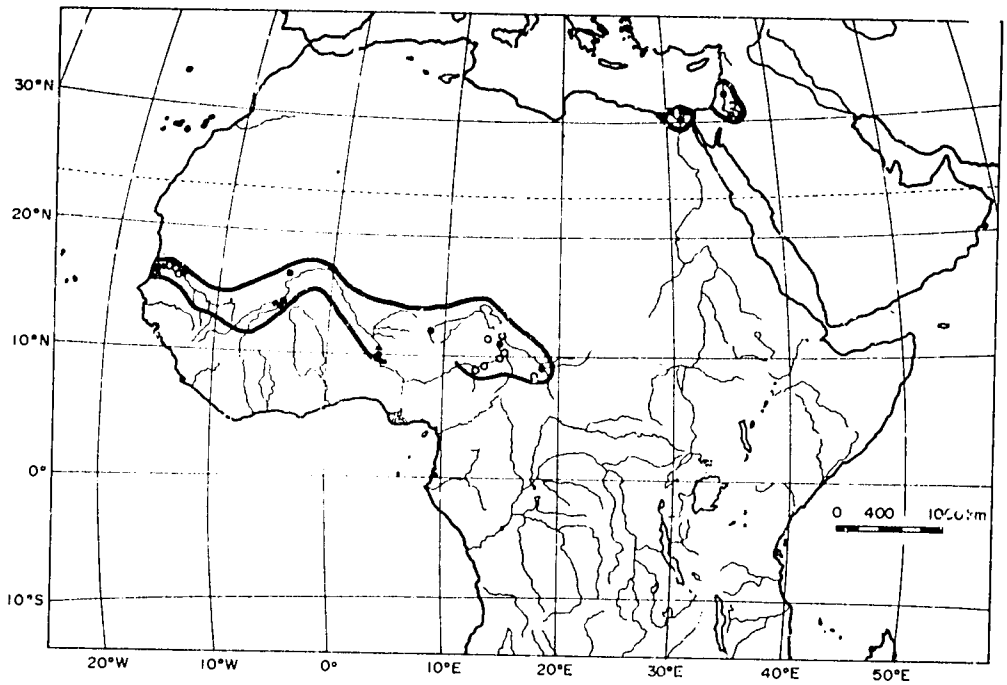

Fig. 9. Distribution of *Oreochromis aureus*. Black dots indicate samples checked personally by the author; white dots indicate published records regarded as reliable.

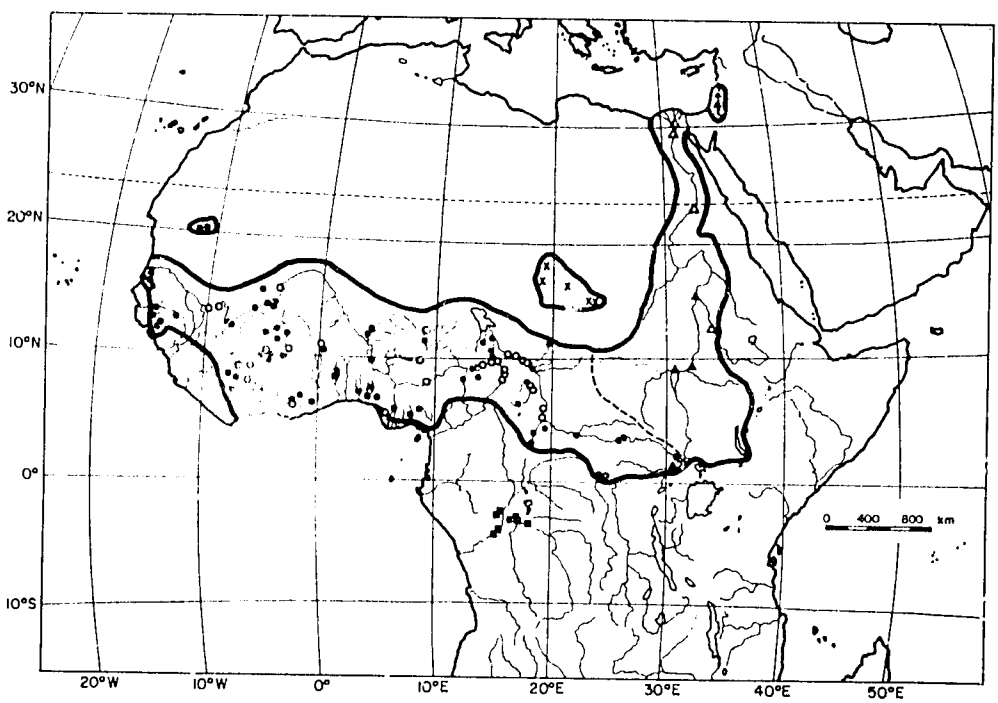

Fig. 10. Distribution of *Sar. therodon galilaeus: S. galilaeus galilaeus*, ▲, △; *S.g. multifasciatus*, ●, ○; *S.g. borkuanus*, x; *S.g. boulengeri*, ■. Closed symbols indicate samples checked personally by the author; open symbols indicate published records regarded as accurate. (cf. Trewavas (1983), Fig. 36, p. 95 – Editor).

Implications for tilapia nomenclature

There are some implications here for tilapia nomenclature. It reflects the natural situation, not the world of aquaculture. A species is never stable in nature. It may die out or spread to form other species. In taxonomy, species with a very restricted distribution are considered 'young' species and those with a wider distribution are considered 'old'. Once a species has a very wide distribution it may 'fall apart'. This happens frequently with fish species when water bodies become mutually isolated and the separate populations change through new mutations and genetic flux. The recognition of the level of differentiation necessary to assign a given population to a new species, subspecies or strain is a matter of opinion and controversy amongst taxonomists - the classic splitters vs. lumpers debate. It has been observed for some fish, amphibians, birds and even monkeys that when previously reproductively isolated allopatric species are brought together by, for example, geological events, they sometimes start interbreeding. This confusing situation has led to the concept of a 'supraspecies' - a widely distributed species that is 'falling apart', the isolated components of which do not freely interbreed unless brought together by some hazard or event.

The natural distribution patterns of tilapia suggest such a situation. For example there is allopatry between *T. zillii* from northern Africa, *T. rendaili* in the more southern savannah and *T. congica* in the swampy rainforest (see above), but in Lake Victoria where both *T. zillii* and *T. rendalii* have been introduced, there are some natural hybrids (Welcomme 1966, 1967). *T. buttikoferi* extends from southern Sénégal through Guinea and Guinée Bissau to Liberia. *T. brevimanus* which is from a rather different morphological group has about the same distribution (Fig. 11). They are sympatric but do not interbreed and are regarded as old, well-established separate species. Contrast the mouth brooders used in aquaculture; for example, in East Africa *O. spilurus niger* and *O. spilurus spilurus* - their most important feature is that they are allopatric (Fig. 12). *O. mossambicus and O. mortimeri* are also allopatric but interbreed where they meet in the lower Athi, Kenya [but not *O. niloticus* and *O. aureus* in the Egyptian coastal lakes and Nile Delta, Egypt, where these are sympatric - Editor].

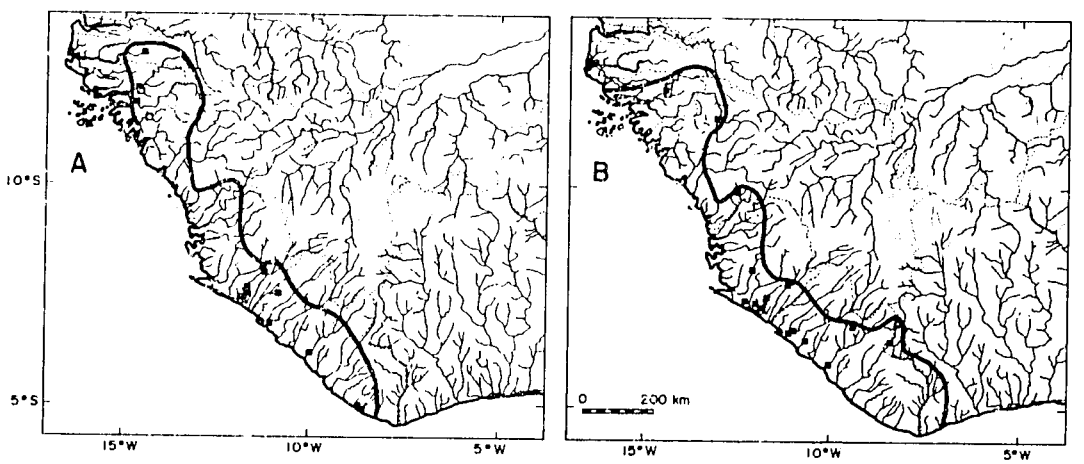

Fig. 11. Distribution of A. *Tilapia buttikoferi* and B. *Tilapia brevimanus*.

In nature we have a large number of allopatric species inhabiting different river systems or different parts of river systems - sometimes encroaching slightly on each other but rarely hybridizing, unless brought together artificially, for example in fishponds, when they then often hybridize rather easily. This is further evidence for regarding tilapia as a supraspecies. By bringing different tilapias together through transfers, we are undoing the work of nature: selection over many thousands of years.

The conventional system of nomenclature (genus, species, subspecies) is fine for describing a natural situation, but inadequate for an aquaculture situation in which interbreeding can occur.

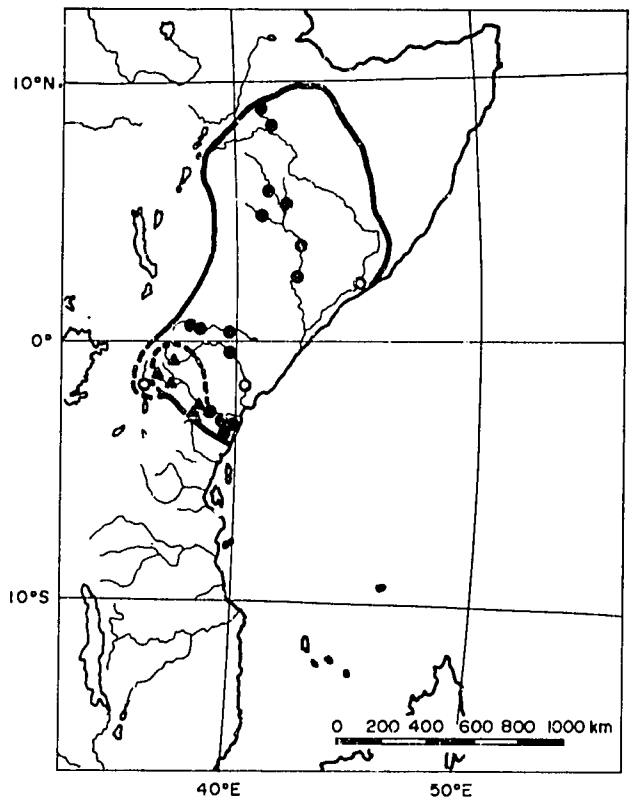

Fig. 12. Distribution of *Oreochromis spilurus*: *O. spilurus spilurus*, (●), (○); *O. spilurus niger*, (▲). Closed symbols indicate samples checked personally by the author; open circles indicate published records regarded as reliable.

It seems inappropriate to use a Latin binomen for many of the tilapias being cultured. For example, red tilapias are often described as a cross between two species but in reality their breeding history is far more complicated than a one female x one male cross. For such fish, Latin names may as well be discontinued. Moreover, now that the tilapia supraspecies has become so mixed up by transfers for aquaculture and stocking, it is probably time to drop Latin names for cultured tilapias altogether and to revert to some other system of codenames. The nomenclature that applies to natural populations has ceased to be a useful tool for labelling cultured tilapias.

Implications for the protection and utilization of tilapia genetic resources

From the examples given above, it is clear that the natural distribution patterns of tilapias are the result of evolution and reflect some hazard factors - for example, one species excludes another - but they are not a good indicator of 'ecological amplitude', i.e., environmental adaptability. If we find a tilapia in a natural setting, it is obviously adapted to live there but this is not proof that this is its most favorable or most typical habitat (even with respect to gross differences such as salt- or freshwater). Moreover, the strains now in use in fish culture are not generally representative of the whole species, for example *O. macrochir* (see above).

With regard to the consequences of natural distribution for protection of genetic resources, it is clear that there is a tremendous range of material with both good and bad characteristics from a culture viewpoint. How can we approach this problem? At the First International Symposium on Tilapia in Aquaculture (ISTA I) (Fishelson and Yaron 1983) recommendations were made to protect 'wild strains' of tilapia. Clearly not all natural waters in Africa can be protected. Uncontrolled transfers of tilapia continue throughout Africa, with the possible exception of the

Sahelian region. Introduced fish have hybridized with local strains. A huge effort would be required to document this and could not possibly capture all the information required. Many transfers have been undocumented. However, efforts could be made to protect some important resources. *O. niloticus* is clearly important. It reaches a large size in alkaline waters such as Lake Turkana, but smaller sizes in West Africa. The evaluation of different strains of *O. niloticus* merits a large effort.

Summary

a. The natural distributions of tilapia species are not good indicators of their potential use in different culture environments.

b. The natural distributions of tilapia should be thoroughly documented so as to learn where important wild strains survive and how to protect them.

c. Tilapias behave like a supraspecies, but aquaculturists are undoing the work of natural evolution by transfers and bringing species together. Therefore a new system of strain identification and nomenclature is needed for cultured tilapias. This will have to involve techniques other than the purely morphological descriptions used for natural populations.

Discussion

Dr. Lowe-McConnell noted the large number of tilapia species available, the small number actually used for aquaculture and the very small founder populations from which most cultured stocks have been derived.

Dr. Smitherman asked whether the natural distribution of *O. niloticus* was really of no value in searching for more cold-tolerant fish for culture.

Dr. Thys van den Audenaerde replied that fish living in a cold area obviously had cold-tolerance, but that fish from warmer areas of the natural distribution may also have good cold-tolerance. The natural distribution is not a reliable guide to the environmental tolerance properties of fish moved outside their natural distribution. *O. mossambicus* is a good example. It will live in seawater or freshwater. It would clearly be sensible, however, when looking for cold-tolerant fish to collect from the colder areas. *O. mossambicus* is also extremely cold-tolerant in saline waters; for example at Algoa Bay, South Africa.

Mr. Nguenga reported that workers in Cameroun are unsure of the origin of some of the Cameroun stocks of *O. niloticus* and asked the opinion of Dr. Thys van den Audenaerde.

Dr. Thys van den Audenaerde replied that *O. niloticus* was brought from the Benoue River to the fishponds at Yaoundé and from there was spread throughout the country: first to a small dam in Tibati and from there to the larger dam at Mbakaou. This strain then came down the Sanaga River. From the 1970s it could be found at the Nachtigal Falls and even down to Edea. This was a result of escapes from Tibati. It is not clear, however, whether the same strain has been spread to other parts of Cameroun. The CTFT/FAO subsequently brought an *O. niloticus* founder stock to Cameroun from Bangui, Central African Republic, in 1963. The origin of this was the Djoumouna Station, near Brazzaville, Congo. *O. niloticus* is native to the northern rivers. Benoue and Logone-Chari, of Cameroun.

[An *O. niloticus* 'strain' was sent in 1958 to Cameroun from the Landjia Station, Central African Republique. J. Bard started culture trials with *O. niloticus* at Yaoundé in April 1959 (M.M.J. Vincke, pers. comm. to Editor)].

Dr. Pullin welcomed Dr. Thys van den Audenaerde's suggestion for devising a new system of naming cultured tilapias and drew attention to the continuing problem of researchers using poorly characterized material of largely unknown origins. Researchers from Japan, the University of the Philippines and ICLARM have shown that many populations thought to be *O. niloticus* are in fact introgressed hybrids with *O. mossambicus* (Taniguchi et al. 1985; Macaranas et al. 1986). Moreover, most researchers and culturists take the word of suppliers for the identity of fish and often fail to check it against published descriptions such as Trewavas (1983). There will be problems, however, in implementing a new nomenclature system. Not least among these

is the temptation for breeders to label their 'strains' with the names of institutions, companies and individuals and to claim that they are 'high performance', 'selected', 'improved', 'superior', etc. - in the absence of any scientific evidence for genetic gain. Dr. Pullin asked whether anyone present knew of internationally recognized current systems operating for other species that could be used for tilapias and that would avoid such problems.

Dr. Thys van den Audenaerde pointed out that strain coding in rice and other crops is well-established and seems to have avoided such problems of self-interest. He also noted that in agriculture, where major genetic advances had been made (e.g., rice, cattle), Latin names are not used. Strain names and numbers are used instead.

Dr. Smitherman agreed that there are dangers in commercial concerns labelling strains and making unsubstantiated claims for their performance. He pointed out that the problem remains of what is a 'strain'? Universities and other institutions have put their names on 'strains' largely to show their origin.

Dr. Villwock mentioned that the International Council for Exploration of the Sea (ICES) has made recommendations for naming breeding strains of salmonids (ICES 1984). A strain registry has also been started for trout (Kincaid 1981). To do this for the tilapias would require a working body of interested persons.

Dr. Payne doubted that many tilapia strains are sufficiently distinguishable and/or stable for a strain nomenclature system and recommended more studies on genetic markers to label strains; for example, the curly forelock of all Hereford strain cattle is a good analogy. For tilapias, the homozygous recessive pale *O. niloticus* described by Mires (in press) is an example.

Dr. Thys van den Audenaerde drew attention to the vastly increased difficulty of maintaining strain stability for fish compared to terrestrial livestock and plants. Salmonids interbreed less freely than tilapias and are therefore easier material from which to develop stable strains.

Dr. Harvey mentioned the tremendous plasticity of the tilapias in their responses to different environments and recollected Dr. Thys van den Audenaerde's remarks on the large size of Lake Turkana *O. niloticus* as against some other populations. [For comparisons of the growth rates of wild and cultured tilapias see Moreau et al. (1986) and Pauly et al. (in press) - Editor]. The relative importance of the genetic component of growth potential and response to the environment is a key issue here. The plasticity of the tilapias is shown clearly by the changing responses of sperm cells, i.e., activation by different media in changing environments. *O. mossambicus* sperm cells from freshwater-maintained fish are activated by freshwater whereas if the fish are changed to a saline environment, the sperm cells become best activated by saline media. The change takes place almost overnight.

Ecology and Distribution of Tilapias in Africa that are Important for Aquaculture

Dr. R.H. Lowe-McConnell

Fish transfers

Field biologists have studied tilapias in the great lakes of Africa, farm dams and other waterbodies from 1945 through the 1950s - an interesting period because, as mentioned by Dr. Thys van den Audenaerde, fish culture attempts in Africa were then just beginning. However, the importance of keeping tilapias separate to avoid them hybridizing was not realized. For example, a fisheries officer from Korogwe in Tanzania would take fish over the border to Kenya as a present for a local farmer or official. Such exchanges were common.

Further haphazard transfers of fish should be avoided as far as possible and more research should be done on natural populations. The attitude that because one has 'fish to spare' these should be distributed to others as gifts for stocking waters or for culture has to change. A more responsible attitude is now required.

2. *Species of importance for aquaculture and their distribution*

Drs. Lowe-McConnell and Trewavas concur with Pullin (1983) as to the species of tilapia of greatest importance for aquaculture (Table 1).

Table 1. The most important cultured tilapias: modified from Pullin (1983). Species of very localized importance are omitted.

A. The most widely cultured species and hybrids		Attributes/Comments
1.	*Oreochromis niloticus*	Fast growth, especially in the tropics; versatile feeder
2.	*Oreochromis aureus*	Fast growth; versatile feeder cold-tolerant - but difficult to seine in ponds, so best grown in cages or used as a parental stock for hybridization
3.	*Oreochromis* monosex male hybrids, principally *O. niloticus* x *O. aureus*	Fast growth, especially on pelleted feeds
B.	Other cultured species	
1.	*Tilapia rendalli*	Macrophyte-feeder; potential for polyculture with microphagous tilapias.
2.	*Oreochromis spilurus spilurus*	Fast growth; saline-tolerant; a good grazer on epiphytic algae
3.	*Oreochromis andersonii*	Reasonable growth and cold tolerance
4.	*Sarotherodon melanotheron*	Saline-tolerant; good growth in separate sex culture

The most important group comprises maternal mouth brooders, but *Sarotherodon galilaeus* is used by some culturists and *S. melanotheron* is potentially useful for brackishwater culture. Of the substrate spawners, *T. rendalli* is the main species cultured.

Fig. 13 summarizes the natural distribution of the most widely cultured species and of some other species of interest to culturists. Fig. 14 gives more detail of the natural distribution of the most important single species, *O. niloticus*, and Fig. 15 the natural distribution of *Oreochromis* species in East African rivers.

It may also be worth looking at some of the other lacustrine species for culture potential; for example, four of the five mouth brooders that occur in Lake Malawi, *O. saka*, *O. squamipinnis*, *O. karongae and O. lidole*); *O. variabilis* (now sadly almost displaced from Lake Victoria); the species in the Malagarasi swamps, *O. malagarasi* and *O. karomo* (which also reach a large size); *O. upemba* from the Upemba lakes and other species from east and central African lakes. These lacustrine species, easily recognized by the presence of a genital tassel in the male, all belong to the subgenus *Nyasalapia* (Thys) as distinct from the *Oreochromis Oreochromis* group (Trewavas 1983).

The *Oreochromis O.* group is found mainly in East African rivers. From north to south, this group includes: *O. spilurus* (Somalia/Kenya); *O. korogwe*; *O. urolepis; O. placidus* and then the southernmost, *O. mossambicus*. Some of these have recognized subspecies. This is often because the species has two forms; one that can tolerate salt water in the near-coastal reaches of rivers and another in the upper reaches in freshwater. For example, *O. spilurus spilurus* in the lower Athi and *O. niger* in the upper Athi. *O.s. niger (Tilapia nigra)* was used in the early work on fish culture at the Sagana station, Kenya. It has now virtually disappeared as a naturally occurring subspecies. Attempts by Drs. Lowe-McConnell and Trewavas to locate naturally occurring *O.s. niger* in 1981 failed. The reason is probably the extensive mixing of riverine populations due to escapees from aquaculture projects.

'O. hornorum' is now thought to be a subspecies of *O. urolepis* (the species found in Tanzanian coastal rivers) and was also called the 'tilapia from Zanzibar' (Hickling 1960). When first introduced to Asia it was thought to be 'new blood' of *O. mossambicus* to supplement the local stock. Dr. Hickling used 'hornorum' introduced to the Fish Culture Research Station at Malacca, Malaysia, for the original work on monosex male hybrid crosses. It has seen extensive use in experimental aquaculture and in some production in Brazil (Lovshin 1982). It is now thought that *O. urolepis hornorum* was probably originally introduced to Zanzibar from the Wami River system in Tanzania before proper records of fish transfers were started.

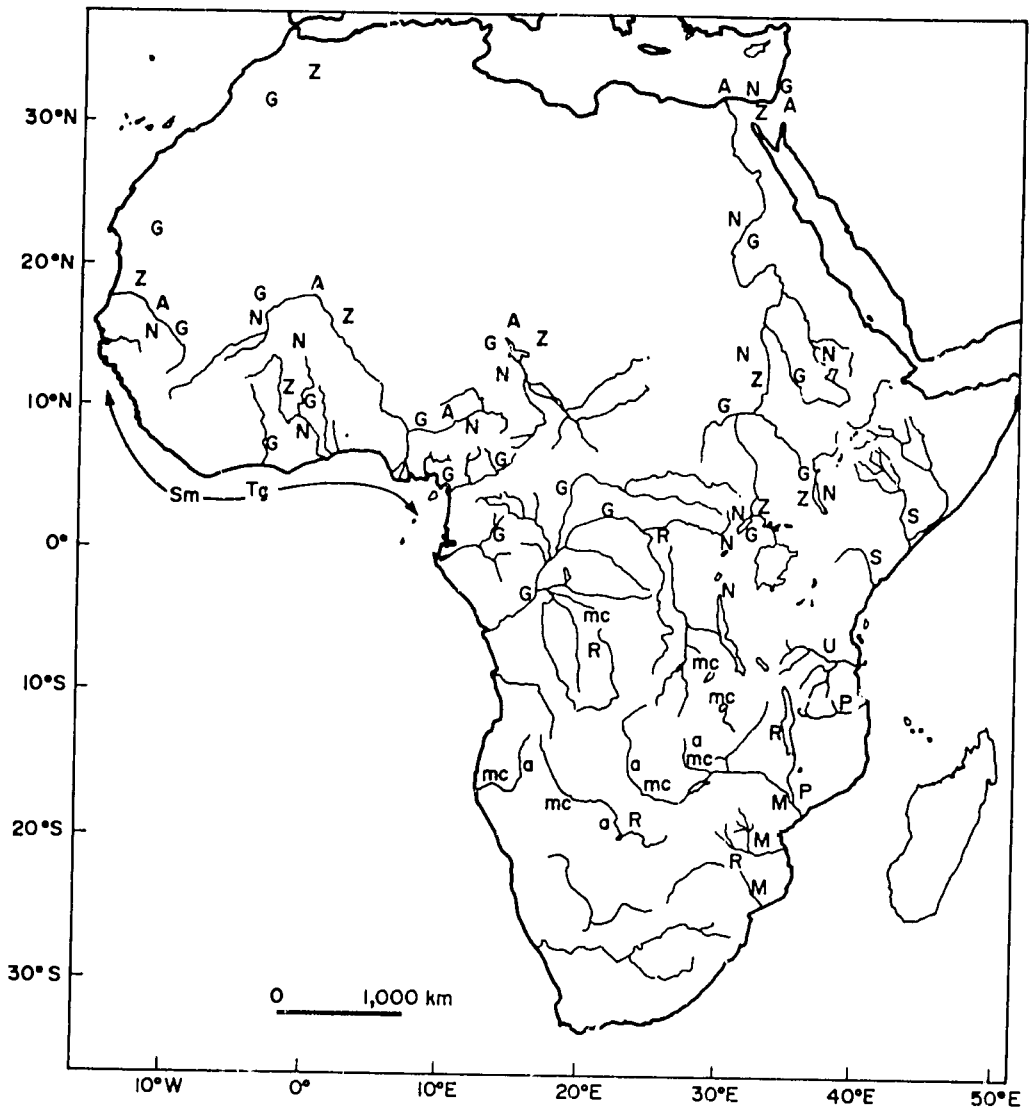

Fig. 13. The natural distributions of tilapias used in aquaculture. The species *Oreochromis niloticus* (N), *O. aureus* (A), *Sarotherodon galilaeus* (G) and *Tilapia zillii* (Z) all have a Soudanian distribution from West Africa to the Nile valley. *O. aureus*, sympatric with *O. niloticus* in the Nile delta, extends to the Jordan valley. *T. rendalli* (R) is a southern form, widely distributed in Central Africa, as is *O. macrochir* (mc) and *O. andersonii* (a). *S. melanotheron* (Sm) and *T. guineensis* (Tg) inhabit West African coastal lagoons. Distributions of east-flowing river species (including *O. spilurus* (S), *O. urolepis* (U) and *O. mossambicus* (M)) are shown in Fig. 15. Data from Trewavas (1983).

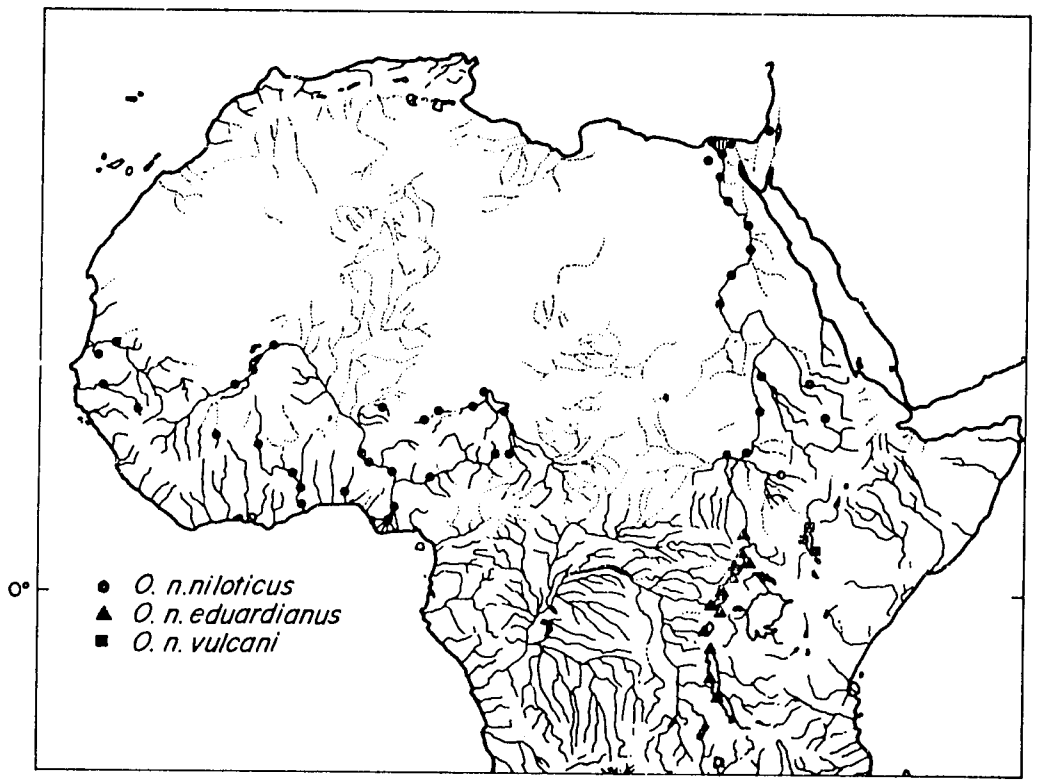

Fig. 14. Natural distribution of the subspecies of *Oreochromis niloticus* used in aquaculture. After Trewavas (1983), who gives details of the distribution of other subspecies.

O. placidus is found together with *O. mossambicus* in the lower Zambezi. It would be useful to study the characteristics of these species before any further transfers and mixing of species occur in this system. *O. mortimeri* is a closely related freshwater species further inland. Other species worth mentioning are *O. pangani* from the Pangani River and *O. shiranus shiranus* and *O. sh. chilwae* from Malawi.

All these riverine species lack a genital tassel in the male and (with the exception of *O. niloticus*) are easily distinguished by the enlarged jaw of the mature male.

The status of the endemic *Oreochromis tanganicae* in Lake Tanganyika is unclear. *O. niloticus* is also found in Lake Tanganyika, having come in from Lake Kivu, as a result of natural changes in topography.

Regarding hybridization in natural waters, we have no clear examples. However, when two species have been introduced to a lake, for example, in Lake Naivasha (*O. spilurus niger* and *O. leucostictus*) these have hybridized (see Elder et al. 1971; Siddiqui 1979).

Further information on Oreochromis niloticus and its relationships with other species

Oreochromis niloticus and *O. aureus* are by far the most important species for aquaculture. Their distributions extend from the Nile system to West Africa as a result of the much wetter conditions during Pleistocene times. *O. aureus* also extends to the Jordan Valley.

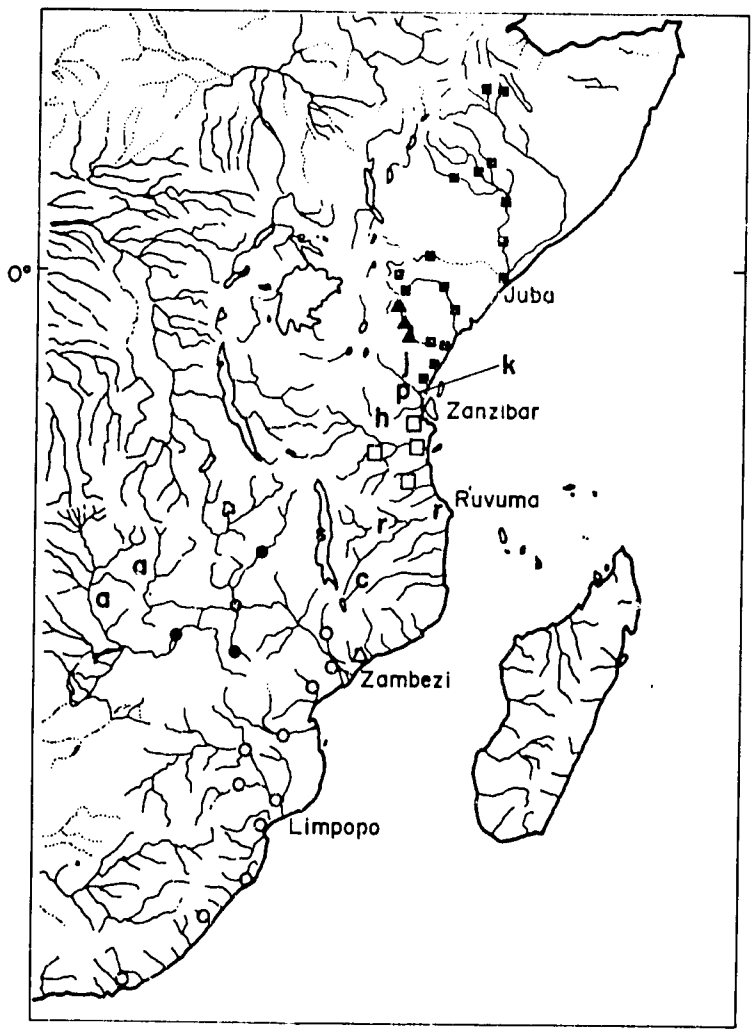

Fig. 15. The natural distributions of *Oreochromis* tilapias in river systems of eastern Africa. Most species in lower reaches live in freshwater but can withstand brackish- or saltwater.

Somalia and Kenya: *O. spilurus* (▪) (*O.s. niger* in the Upper Athi (▲)); Tanzania: Lower Pangani *O. korogwe* (k) with *O. pangani* (p) upriver and *O. jipe* (j) in Lake Jipe; *O. urolepis* (▫), (*O.u. hornorum* (h) in the Wami and Zanzibar); *O. placidus ruvumae* (r) in Ruvuma; Zambezi system: Lower Zambezi, *O. placidus* (△), *O. mossambicus* (○) (also found in coastal rivers of southern Africa), replaced by *O. mortimeri* (●) Middle Zambezi; *O. andersonii* (a) Upper Zambezi and Kafue; *O.s. chilwae* (c) in Lake Chilwa; *O. shiranus* in Lake Malawi (s). Data from Trewavas (1983).

For *O. niloticus*, Trewavas (1983) recognizes a number of subspecies of which three groups are of interest to aquaculturists (Appendix I, Fig. 1). The *O.n. niloticus* group extends from West Africa to Egypt. There is also a group from the lakes of the western rift valleys called *O.n. eduardianus* and *another called O.n. vulcani* from Lake Turkana (formerly Lake Rudolf). Other subspecies recognized by Trewavas are very localized (see figure in Pullin and Capili (in press), Appendix I).

Early work on the maturation and growth of *O. niloticus* in East African waters is reviewed by Lowe-McConnell (1982). The largest fish were found in Lake Turkana. They had excellent growth rates. However, a population of these fish trapped in a smaller waterbody on an island in the lake (crater Lake 'C') remained smaller in size. A population of black, somewhat larger fish in another crater lake (crater lake 'A') gave rise to the name *'vulcani'*.

In Lake Albert, which is connected with the Nile River, the *O. niloticus* (*O. n. eduardianus* according to Trewavas 1983: p. 160) also grow very large, but populations trapped in lagoons (for example the Buhuku lagoon) are of very small fish. In such populations, the maturation size is also very small and the females are much smaller than the males. All such fish have very poor condition factors compared to fish from the main lake. However in the main lake, the males and females grow to about the same size and mature at about the same size. Therefore the same 'strain' grows to a large size in the lake but to a much smaller size in the lagoons. Lagoon fish may grow large once they gain access to the main lake; this phenomenon has been seen elsewhere (with tilapias in Lakes Chilwa and Rukwa) and also with fish transferred to ponds at Sagana, Kenya.

Lake Victoria originally had two naturally occurring species - *O. esculentus* and *O. variabilis*. It was then stocked with *T. zillii* from Lake Albert, the intention being to introduce a herbivorous species to eat the abundant marginal vegetation. However, the shipment of *T. zillii* also included (unintentionally) some *O. niloticus* and *O. leucostictus*. Moreover, some culture trials were made with *O. niloticus* at Kajansi, Uganda, in an area that drains into Lake Victoria and *O. niloticus* probably got into the lake from this source as well. Therefore Lake Victoria received first the subspecies *O.n. eduardianus*. Verbal reports suggest that further introductions have been made from Lake Turkana (*O.n. vulcani*). *O. niloticus* were also seen in 1967 in the Mwanza prison ponds bordering the south end of the lake (A.I. Payne, pers. comm.).

The general result in Lake Victoria has been that *O. niloticus* has displaced or hybridized with the endemic *O. esculentus* (almost completely) and has flourished, reaching large sizes. *O. leucostictus* has also become well-established, mainly in the swampy marginal areas. *T. zillii* has also done well and has largely displaced the endemic *O. variabilis* as discussed by Fryer and Iles (1972: p. 263). More recent introductions of the Nile perch *(Lates niloticus)* are also having an effect. This predator has severely depleted populations of some of the native haplochromine species (Barel et al. 1985) [but does not appear to have seriously affected the tilapia populations (J.D. Balarin, pers. comm. to Editor)]. Thus the species assembly in Lake Victoria has been completely changed by introductions (Welcome 1966, 1967) and changes are still occurring. It is perhaps significant that the most successful tilapia in Lake Victoria is now *O. niloticus* or an *O. niloticus* hybrid. *O. niloticus* co-exists with *Lates niloticus* in the Nile, Lake Albert, Lake Turkana and Lake Kioga.

[Despite its displacement by *O. niloticus* in Lake Victoria. *O. esculentus* now predominates over the naturally occurring *O. pangani* and *O. jipe* following its introduction into the Nyumba ya Mungu dam on the Pangani River, west Tanzania (A.I. Payne, pers. comm. to Editor)].

In Lake George, Uganda, *O. niloticus* (*O.n. eduardianus)* grows to a large size and maintains good condition, but fishing pressure reduced the size and maturation size over an eleven-year period (Gwahaba 1973; Lowe-McConnell 1982).

Conclusions

One possible conclusion from all these observations is that environmental factors so influence the growth performance and maturation size of tilapias that it is of little use for culturists to rush to locations like Lake Turkana to collect large fish as founder populations for aquaculture. However, there does seem to be a growing body of opinion, as voiced in discussions at the Second International Symposium on Tilapia in Aquaculture that fish from such natural populations with large growing individuals can also perform well in culture conditions.

There is a clear need for further research on the relative importance of genetic and environmental factors and their interactions affecting tilapia growth performance and for more research on natural populations before more transfers and mixing take place.

Discussion

Dr. Moreau enquired about the status of tilapia in Lake Kivu. Dr. Lowe-McConnell replied that Lake Kivu has a native *O. niloticus* (*O.n. eduardianus*).

Dr. Thys van den Audenaerde agreed and mentioned that the first specimen was collected in 1890 two years after the discovery of the lake and is lodged in the British Museum (Natural History). It resembles the Lake Edward *O. niloticus*. Lake Kivu is a natural dam-lake formed by volcanic activity. It is probable that riverine *O. niloticus* extending into Lake Edward were trapped in Lake Kivu when it became separated. Later on, Lake Kivu rose and overflowed. Therefore the same subspecies *(O. niloticus eduardianus)* now lives in the Ruzizi Valley and in Lake Tanganyika, where it stays inshore, not in the main lake. From 1950, *T. rendalli, O. macrochir* (first the Luapula-Mweru strain and more recently the Kafue River strain) have been introduced for fish culture purposes around Lake Kivu. These have escaped and are now established in the lake. There has been some hybridization between *O. niloticus eduardianus* and *O. macrochir* in the lake such that it is now not possible to assign some specimens to one or other of these species. Therefore Lake Kivu now contains one native species (*O.n. eduardianus*), three introduced tilapias (*T. rendalli* and two strains of *O. macrochir*) and hybrids.

Dr. Coche mentioned *O. andersonii*, a species of increasing importance for aquaculture in Zambia.

Dr. Lowe-McConnell agreed that this is an important species and pointed out that where such good species exist (for example *O. andersonii* and *T. rendalli* are available in Botswana) it is not wise to introduce exotic species like *O. niloticus* without first assessing the utility of the native species.

Dr. Marshall mentioned that *O. mortimeri* grows to a large size in Zimbabwe.

Dr. Pullin reported that, whatever the merits of *O. andersonii* in Zambia, culturists there have already imported *O. niloticus* and *O. aureus* from Israel and *O. niloticus* from Stirling University. There will probably be escapes from farms into the Kafue system.

Dr. Thys van den Audenaerde reported that the Kafue strain of *O. macrochir* was introduced under the name *andersonii* to the fish culture ponds at Kipopo, Katanga (now Shaba) near Lubumbashi, Zaïre. Wild *O. macrochir* in this vicinity appear different (more elongated) than the Luapula-Mweru strain. The error in nomenclature has been corrected, but still survives in some literature. *O. mortimeri* was introduced to Katanga (Shaba) under the name *'mossambica'*. It has not spread much in Upper Shaba. It is found in the vicinity of the Lufira dam. Therefore *O. mortimeri* has reached the Zaïre system. Its current status and future spread are matters of conjecture. It is probably still called *'mossambica'* because of the erroneous nomenclature of the introduction.

Dr. Moreau ascribed some of the different growth patterns of *O. niloticus* in natural waters to differences in diet-type and digestibility of available phytoplankton.

Dr. Lowe-McConnell agreed and said that the populations in lagoons and small waterbodies usually have a poor diet. Food shortage seems to be the main factor in limiting size. Blue-green algae are the most important source of food for *O. niloticus* (Moriarty 1973; Moriarty and Moriarty 1973). Alkalinity cannot be the major factor promoting good growth in this case as the lagoons and small waterbodies are as alkaline or more alkaline than the main lakes.

Dr. Harvey asked which species other than *O. niloticus* digest blue-green algae?

Dr. Marshall stated that *O. mossambicus* and *O. macrochir* can digest blue-green algae and that this ability is probably widespread among tilapias.

Session II. The Status of Wild and Cultured Tilapia Genetic Resources in Various Countries

Chairman: Dr. R.S.V. Pullin

Africa

Cameroun

Mr. D. Nguenga

Aquaculture development has a 40-year history in Cameroun. It has been practised largely at a subsistence level because of the absence of any fish husbandry tradition. Efforts to build the first fishponds were started in 1947. Over 12,500 family ponds of around 200-400 m^2 were in operation in the 1960s. Today only 3,000 to 5,000 are functional (B.P.N. Satia, pers. comm.). The decline is attributed to a certain number of factors:

- The lack of management ability has adversely affected progress in aquaculture development. The hopes placed on tilapia culture during the 1950s to contribute significantly to protein production turned to disillusionment because of excessive reproduction in culture ponds.
- Pond construction has been poor and techniques inefficient (Balarin 1985).
- There have been budget restrictions and reductions in bilateral aid.

Marine and inland fisheries in Cameroun are now approaching overexploitation. Every year nearly 30,000 t of fish are imported to satisfy the protein requirements of the population. With the ever-increasing need for cheap sources of animal protein, aquaculture offers a viable solution and can be advanced as an additional source of protein supply.

Of the indigenous tilapias, Balarin (1985) reported that *Sarotherodon galilaeus, Tilapia tholloni, T. margaritacea* and *T. zillii* have been tested. All performed poorly and reached only a small size and efforts were soon abandoned.

The most important wild populations of *Oreochromis niloticus* are found in the northern part of Cameroun (Fig. 16). The mean temperature here is above 25°C and is ideal for year-round warmwater fish production. However, there are few perennial streams here and no fish culture stations. This region is drained from the extreme north by two major drainage basins, Chad and Niger. The Chari and Logone Rivers are tributaries of the Chad basin. The Benoue and Faro Rivers belong to the Niger basin. Two important barrages, Maga and Lagdo, have recently been built on the Logone and the Benoue, respectively.

Oreochromis niloticus has also been introduced to Cameroun from Bangui, Central African Republic, in 1975. *O. macrochir* (ex-Congo), *T. rendalli* (ex-Zaïre) and *T. zillii* (ex-Congo) were also introduced early in Cameroun's history of fish culture and are established to varying degrees in natural waterways (Balarin 1985).

[These introductions of *T. rendalli* and *T. zillii* are not recorded in Welcomme (1981). A "1950's" introduction is recorded from the Congo and a *T. rendalli* introduction from an unknown source in 1953. *T. zillii* is not mentioned - Editor].

O. niloticus is now the most important species being used in aquaculture and is used in fish stations throughout the country. The greatest concentration of fishponds is in the northwest and the western provinces where there are abundant perennial streams. The most important cultured populations of *O. niloticus* are found here. There are not many important populations of tilapia in open waters in the south, because here the temperature is usually below 22°C.

Discussion

Dr. Pullin invited discussion on the tilapia genetic resources of Lake Chad and their importance for aquaculture.

Mr. Nguenga said that *S. galilaeus* and *O. niloticus* are the most important species present. The lake is presently being overfished and there is scope for restocking programs. The Ministry of Livestock, Fisheries and Animal Industries in Cameroun has a station at Kousseri that collects

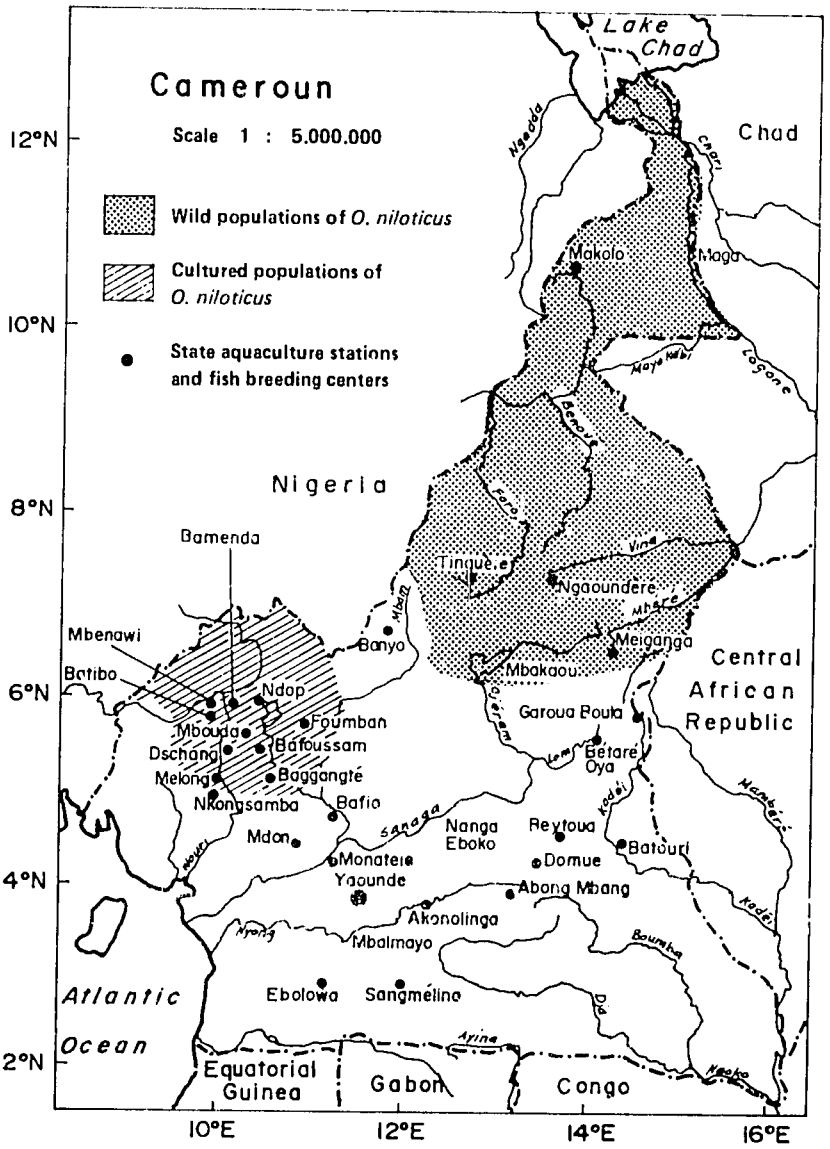

Fig. 16 Distribution of the most important wild and cultured populations of *Oreochromis niloticus* in Cameroun.

data on Lake Chad fisheries. These data are still fragmentary because of the lack of field facilities and qualified manpower. *O. aureus* is known to be present in Lake Chad and the Logone swamps.

Côte d'Ivoire

Brackishwater culture
Mr. C. Adou

In Côte d'Ivoire, the first trials with tilapia in brackishwater culture were done by the Centre Technique Forestier Tropical (CTFT) in 1978-1979 with *Oreochromis niloticus*. This species definitely has the best growth performance in brackishwater in Côte d'Ivoire. However, despite its good growth there are a lot of problems because of disease and mass mortalities even in moderate salinity (5 ppt). The reason for these mortalities is still not clearly understood.

Experiments have been made at Layo (Fig. 17) to evaluate the aquaculture potential of two local brackishwater tilapias, *Tilapia guineensis* and *Sarotherodon melanotheron*, which are naturally adapted to the coastal lagoon environment.

The growth of these two species has been compared both in mixed and monosex intensive culture, using cages or pens (known as 'enclos'). The results show that the good performance is obtained with *S. melanotheron* male monosex culture. However, even in this case, the economic viability of culturing this species in intensive culture is restricted by poor conversion efficiency of the pelleted feed supplied (31% protein). *S. melanotheron* is more adapted to grazing on epiphytic algae and *aufwuchs*.

Tilapia culture in brackishwater lagoons in Côte d'Ivoire is therefore problematical. An exotic species grows well but survives poorly whereas endemic species (*S. melanotheron* and *T. guineensis*, which are well adapted to the lagoon environment) give either poor growth or feed conversion (Table 2).

Experimental aquaculture with *T. guineensis* has now been abandoned. Further work with *S. melanotheron* is proceeding along two lines: 1) trying to elaborate a more cost-efficient artificial feed to improve growth and feed conversion ratio in intensive culture and 2) trying to develop less-intensive culture methods to reduce or even eliminate the use of artificial feed.

In this respect, the possibility of combining culture in 'enclos' with the 'acadja' technique (brushpark fisheries, as used in Bénin) is being studied. Acadjas are placed in shallow lagoon waters. They serve as a shelter for fish and as a substratum for the development of algae and

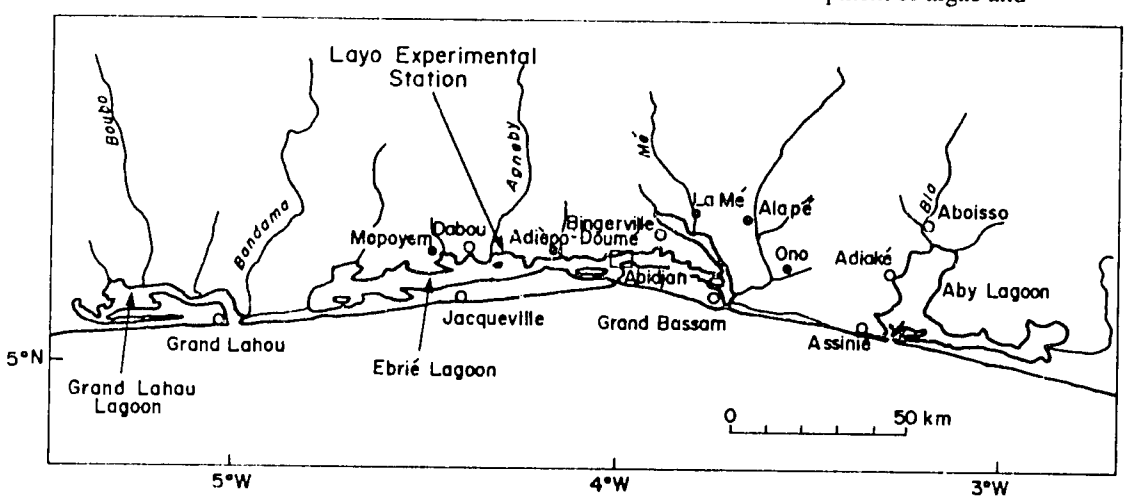

Fig. 17. Map of coastal Côte d'Ivoire showing major lagoon systems and rivers and the location of the Layo experimental station for brackishwater aquaculture.

Table 2. Performance of *Oreochromis niloticus, Sarotherodon melanotheron* and *Tilapia guineensis* in cage culture in brackishwater (5 ppt) in Côte d'Ivoire: stocking density = 20/m^3. Growth performance was followed between 10 and 150 g). Data supplied by M. Legendre, Centre de Recherches Océanographiques, Abidjan (Legendre 1983).

	Growth rate (g/day)	Mortality %	Feed conversion ratio
O. niloticus	1.2 - 2.5	> 80 (after 4 months)	1.26
S. melanotheron	0.3 - 1.2	15 (after 10 months)	> 5
T. guineensis	0.2 - 0.8	13 (after 10 months	> 5

microorganisms: valuable foods for fish like *S. melanotheron*. In Bénin, *S. melanotheron* is the major species caught in the acadjas.

Last year, the first trial was made with 'acadja-enc os' and the results gave an extrapolated annual production of 7 t/ha of *S. melanotheron* without any input of fertilizer or of artificial feed. This result is very promising. The system now needs improvement particularly to determine the best stocking density and the density and size of the acadja relative to the stocking density and size of the 'enclos'.

Further research on brackishwater tilapia culture in Côte d'Ivoire was recently initiated by the CTFT. It involves the culture of exotic tilapias, mostly *O. aureus* and hybrids (*O. niloticus x O. aureus, O. niloticus x O. urolepis hornorum* and *O. mossambicus x O. urolepis hornorum)*, in brackish lagoon waters.

Freshwater culture
Mr. C. Nugent

Natural populations

The Côte d'Ivoire has the following native tilapias: *Oreochromis niloticus*, restricted naturally to a few northern streams; *Sarotherodon galilaeus; S. tournieri; S. melanotheron* and, in brackishwater lagoons, *Tilapia brevimanus, T. mariae, T. guineensis* and *T. zillii* (Daget and Iltis 1965; Albaret and de Merona 1978).

Introductions

The current distribution of tilapias in the Côte d'Ivoire is dominated by the results of introductions of *O. niloticus*. This has become the most important species for inland fisheries and for aquaculture. *S. galilaeus* is now rarely found in catches of the major lake fisheries. It was formerly abundant. The Côte d'Ivoire has no natural lakes, but there are many man-made lakes for hydroelectric and/or irrigation purposes. *O. niloticus* has been introduced into all such lakes, whatever their size. Most of the *O. niloticus* that have been spread throughout the country are derived from stocks of the fish culture station at Bouaké (formerly run by the CTFT and now by the Institut des Savanes-IDESSA). These are the so called 'Ivory Coast' or Bouaké strain'.

Introductions of tilapia stocks to the Côte d'Ivoire have been carried out on many occasions since the mid-1950s (Moreau 1979b); transfers of these stocks to other countries has also occurred regularly. Among the early introductions were *O. niloticus, O. macrochir, T. rendalli* and *O. urolepis hornorum. O. macrochir* was introduced in 1958 (from the Djoumouna center, Brazzaville) and this stock still exists in Bouaké. *T. rendalli*, introduced from Brazzaville (1957) has now disappeared.

O. urolepis hornorum was first introduced in 1967 (40 juveniles) from the Fish Culture Research Station, Batu Berandam, Malaysia. They were breeding by December 1967 and were used for hybridization experiments. By 1972 this stock had become completely mixed and for the hybridization experiments referred to above by Mr. Cissé Adou a new stock of *O. urolepis*

hornorum was introduced to Bouaké in 1981 from Auburn, USA, derived from the original stock present in Bouaké from 1967, from where they had transitted via Brasil and USA before returning!

In 1981, *O. aureus* (of Israeli origin) was introduced from Tihange, Belgium. *O. mossambicus* was introduced from Mozambique also in 1981. The hybrid offspring of these stocks have been used by some farmers around Bouaké and in the lagoons around Abidjan.

By far the most important introduced species is *O. niloticus*. There are natural populations of *O. niloticus* in tributaries of the Black Volta in the northeastern corner of Côte d'Ivoire and in tributaries of the Niger River in the northwest corner. The strain that is now cultured and is currently called 'Ivory Coast strains' has developed at Bouaké where there are no natural populations of *O. niloticus*.

There is some confusion over the early introductions of *O. niloticus* to Bouaké. The first introduction was in 1956 from 'la mare aux hippos' in what is now Burkina Faso. This is a sizeable and fertile lake in the Black Volta catchment area. There was a second introduction from the same source via the station at Bérégadougou, Burkina Faso, sometime in 1966-1968.

There was definitely an introduction of *O. niloticus* originating from the River Nile. This was done to compare Nile fish with the existing strain in Bouaké. The introduction of 17 juveniles (5 females and 12 males) was made from the Kajansi station, Uganda (near Kampala) in June 1968. They began to breed in July.

In 1969, the Bouaké station staff experimented with *O. niloticus* x *O. urolepis hornorum* and *O. niloticus* Volta x *O. niloticus* Nile crosses. After 1971, the Nile and Volta *O. niloticus* stocks became mixed. Therefore the *O. niloticus* shipped to Brazil with *O. urolepis hornorum* in 1971 may have been a mixture of Nile and Volta strains (see also Dr. Moreau's comments on p. 25).

O. niloticus has now been spread throughout the Côte d'Ivoire. The genetic identity of the transfers (Volta, Nile, Volta + Nile or the current 'Ivory Coast strain') depends on the date of the transfers and the extent of hybridization between strains at Boauké. This is not well documented.

A recent introduction was made to Bouaké in March 1987. This involved 11 specimens (8 males, 3 females) from the same area of Burkina Faso as the original introductions (Vallée de Kou, Black Volta catchment). These fish will be compared with the established 'Ivory Coast strain'.

Following widespread stocking of dams and ponds it is now certain the 'Ivory Coast strain' of *O. niloticus* is present in the Volta and Niger catchment areas. It is also in the Bia system, of which a large part of the catchment in Ghana, after stocking of the Ayamé Lakes in 1961 and 1962 (Daget and Iltis 1965; Doudet 1979). It has also been introduced along the Liberian border into the Cavally River catchment area and into the man-made lakes Kossou (R. Bandama) and Buyo (R. Sassandra).

Shipments of *O. niloticus* have been made from Bouaké to many other destinations including Paraguay (1968), Sierra Leone (1970), Venezuela (1971), Brazil (1971), Equatorial and Central Africa and France. More recently fish have been sent to Bénin (1979), Sierra Leone (1978), Guinea (1978, 1983), Mali (1982) and Burkina Faso (1982). This is not an exhaustive list and in some cases fish were further transferred from these to other destinations.

Current status of the 'Ivory Coast strain'

The 'Ivory Coast strain' introductions have normally involved small numbers of fish: at best 200 fish and at worst a few tens of fish. For example, the 'Ivory Coast strain' *O. niloticus* shipped to Brazil in 1971 (60 juveniles) came from a founder population of small size. From there a small number were shipped from Brazil to Auburn University.

At the first International Symposium on Tilapia in Aquaculture, Nazareth, 1983, it was noted in discussion that 'Ivory Coast strain' fish sometimes failed to give 100% male progeny in crosses with *O. urolepis hornorum*. At the Second International Symposium on Tilapia in Aquaculture, Bangkok, 1987, 'Ivory Coast strain' fish were compared unfavorably for growth performance against other strains such as Egyptian fish (Khater and Smitherman, in press). Perhaps bottleneck effects or inadvertent hybridization have changed the characteristics of some of these stocks. Another practice, which may have had a selective effect on some stocks, is

common in countries where the marketing of tilapia is possible at a relatively small size (80 g or even smaller). At harvest, perhaps twice a year, all the larger fish (both sexes) are removed and sold, and the smaller fish are used for restocking (thus becoming the parent stock of the next generation). This selection for early maturity and/or slow growth may be aggravating the phenomenon of stunting. At Bouaké, such continuous harvesting and possible deterioration of the broodstock have not happened to any great extent. Hatchery and production operations are now well separated.

On the positive side, an important attribute of the 'Ivory Coast strain' is its domesticity. It has a 30-year history of use in aquaculture. It is likely to have become well-adapted to handling and to pond conditions in West Africa (which are often very stressful; e.g., low dissolved oxygen, no aeration, water restrictions in the dry season). At Bouaké, 'Ivory Coast strain' *O. niloticus* are very 'quiet' fish and are easy to handle. They rush to be fed whenever anyone approaches the pond. They were found to be very different in these respects from 'Israeli' *O. niloticus* shipped to Bénin, where the two introduced strains were compared: the 'Ivory Coast strain' fed very actively as soon as feed was distributed, whereas the Israeli fish waited until the pellets had sunk. [For such comparisons, an introduced strain should be given at least two generations to adapt to the new environment, i.e., natural selection - Editor].

In Rwanda, the 'Egyptian strain' *O. niloticus* introduced in 1984 is reportedly more popular with farmers than the 'Ivory Coast strain' used formerly (Hanson et al., in press; Moehl et al., in press). Such comparisons should be treated with caution. Differences may be due to better pond management techniques introduced at the same time as the fish strain by the development project and not to genetic characteristics of the fish.

If 'Ivory Coast strain' is ultimately shown to be inferior to other strains, what should be done? It would be a horrendous task to replace 'Ivory Coast strain' stocks throughout all waterbodies in the Côte d'Ivoire. How inferior would the 'Ivory Coast strain' have to be before replacement was considered advantageous?

In a rural setting, however, farmers can do very little of a practical nature towards conservation of genetic resources or towards any deliberate genetic selection. Moreover, many African governments probably would not place fish genetic resources conservation very high on the list of priorities. One cannot be optimistic that many governments will share the concern for protection of natural genetic resources shown by, for example, the Government of Malawi, especially if this means allocating scarce resources to this task.

For rural farmers in Africa, it is probably not very important to strive for the ultimate in tilapia growth performance as measured under ideal conditions. Growth rates in the range 2.0 to 2.5 g/day have been achieved with 'Ivory Coast strain' under good culture conditions but this depends mostly on management. Hardiness and good growth under suboptimal culture conditions are much more important than theoretical maximum growth rates.

Discussion

Brackishwater culture

Dr. Payne commented on the improved results with separate-sex as against mixed-sex culture of *S. melanotheron* and reminded those present that this is a male or bi-parental mouth brooder. He asked about the size at maturation under these culture conditions.

Mr. Adou replied that some matured at a fairly small size (50-80 g) but most matured at around 100 g.

Dr. Coche recalled the results of Campbell (1985) on brackishwater culture of tilapias in the Côte d'Ivoire. He had even tried vaccines against bacterial diseases in *O. niloticus*. He rejected the use of *T. guineensis* and *S. melanotheron* on grounds of their poor growth and finally abandoned the culture site. Mr. Campbell is now working again with *T. guineensis* at the brackishwater station of the African Regional Aquaculture Center, Port Harcourt, Nigeria, where there will be a re-evaluation of this species for aquaculture.

Dr. Guerrero mentioned that brackishwater culture of *O. niloticus* has been investigated at Leganes, Iloilo, Philippines. If the fry and fingerlings are gradually acclimatized to

brackishwater (say 5 ppt/day) this species can be kept at up to 30 ppt. However, bacterial diseases do occur in some ponds, due to a combination of certain environmental factors and abundance of the pathogens in particular ponds.

Dr. Pullin recalled his surprise on a recent visit to Côte d'Ivoire at learning of problems with *O. niloticus* culture in brackishwaters of very low salinity (5-8 ppt), as this species appears to perform adequately in salinities up to at least 15 ppt in various parts of Southeast Asia. There are two ICLARM Technical Reports on saltwater culture of tilapias (Watanabe et al. 1984, 1985). There are three approaches to producing a tilapia for good saltwater culture performance: 1) using a species or strain that is naturally salt-tolerant, 2) acclimatization of freshwater species to saltwater by gradually increasing salinity or using high salt diets or both and 3) genetic methods - hybridization or selective breeding. Most experimental aquaculturists go straight for the hybridization option without adequate attention to options 1) and 2). Continuous production of hybrids is difficult to manage on a commercial scale.

Dr. Wohlfarth asked why the males of *S. melanotheron* grow faster than the females, it being a bi-parental mouth brooder. He had always assumed that it is the brooding habit that causes sexual differences in growth rates in the tilapias. [According to Trewavas (1983: p. 54-55) the females mature at a smaller size; the biggest fish recorded are males - Editor].

There followed an inconclusive discussion in which the general feeling was that male growth superiority was probably a feature of all tilapias (including the substrate spawners) for a number of reasons including reproductive behavior, endocrinology and genetic factors.

Dr. Thys van den Audenaerde asked whether the low fecundity of *S. melanotheron* could pose a problem for its use in aquaculture. It broods less fry than the female mouth brooders.

Mr. Adou said that this has not been studied in the Côte d'Ivoire. However, there have been no difficulties so far obtaining enough fry for experiments. The Côte d'Ivoire has a long dry season and *S. melanotheron* breeds throughout this season.

Freshwater culture

Dr. Wohlfarth said that hybridization work with 'Ivory Coast strain' *O. niloticus* has been done at Dor, Israel, following Lovshin's (1980) report of low fry production from *O. niloticus* x *O. urolepis hornorum* crosses. This suggested reproductive incompatibility. The stocks used in Israel were both imported from Brazil in 1977 so they were the same as those used by Lovshin. The Israeli group confirmed Lovshin's result and found similar low fry production in *O. niloticus* 'Ivory Coast' x *O. aureus* crosses (Hulata et al. 1985). At the time, this was regarded as a negative feature of the 'Ivory Coast' *O. niloticus* because *O. urolepis hornorum* seemed to be the most promising male parent for interspecific crosses with other *O. niloticus* strains, for the purposes of producing 100% male progeny. Also the *O. niloticus* x *O. aureus* cross normally produces high percentages of males and has been the main hybrid farmed in Israel. Obviously, however, as 'Ivory Coast strain' *O. niloticus* gave very low fry production compared to the 'Ghana strain' available in Israel, it was not highly regarded in Israel.

Dr. Hulata reported that use of the 'Ivory Coast strain' at the Dor station was abandoned in 1984.

Dr. Wohlfarth said that this perhaps needed reappraisal as the reluctance to interbreed with other species could also be regarded as a positive characteristic in production systems. For example, the 'Ivory Coast strain' could perhaps maintain its purity even when brought into contact with other species.

Dr. Pullin added a note of caution that the so-called 'Ivory Coast strain' stocks in various collections around the world may be different, according to the history of development of the strain given by Mr. Nugent. These 'strains' held in various institutions have been imported from the Côte d'Ivoire at different stages in the development of the present 'strain'.

Dr. Moreau stated that according to Pierre Lessent, the *O. niloticus* shipped from Bouaké to Brazil on November 23, 1971 were most probably Nile strain. Some mixing of Nile and Volta strains occurred at Bouaké from 1970, but the fish that went to Brazil were probably from an 'unmixed' population.

Dr. Smitherman confirmed that the 'Ivory Coast strain' of *O. niloticus* as studied at Auburn University is more tolerant to the presence of humans and more vigorous in its feeding habits than the Egyptian strain. However, despite its skittishness when disturbed by human beings, the Egyptian strain grows better. The so-called 'Ghana strain', introduced to Auburn from Israel (which from comments made at the workshop could have Ivorian origins) is the most prolific breeder of the three strains, including interspecific crosses, but is the worst of the three strains for growth performance (Khater and Smitherman, in press). Therefore all these strains are probably valuable. The observed populations differ in their behavior, growth performance and reproductive performance under a set of experimental conditions.

Dr. Thys van den Audenaerde recalled that in 1966, pond harvests from Bamoro, just north of Bouaké, consisted mainly of native *S. galilaeus*. He said that *S. galilaeus* was formerly spread from Kokondekro (the site of the IDESSA fish culture station just south of Bouaké) and was used a great deal. However, the native *S. galilaeus* in Côte d'Ivoire is an elongated, not deep-bodied fish, and even from the early days of CTFT work at Bouake, *O. niloticus* was preferred.

Mr. Nugent said that *S. galilaeus* is no longer found at Bamoro.

Ghana
Mr. J.K. Ofori

Distribution of Tilapias in Ghana

Ghana, like other West African countries, has considerable tilapia resources. Irvine (1947) recorded the presence of five tilapias that are now considered commercially important in Ghanaian fisheries and aquaculture: *Oreochromis niloticus, Sarotherodon galilaeus, S. melanotheron, Tilapia busumana* and *T. zillii*. There are two main river basins: the Volta and the southern-western rivers (Fig. 18). The latter include rivers such as the Densu, Pra, Ankobra, Tano and Bia. The Volta Basin includes the Volta Lake and the rivers flowing into it: principally the White Volta, Black Volta, Red Volta, Oti and Pru. The two basins are separated by the Mampong-Bisa-Akwapim-Volta range.

Four of the five species listed by Irvine (1947) are in the Volta although *S. melanotheron* is rare (Denyoh 1969; Petr 1969). *T. busumana* is excluded from the Volta system and is found, together with *S. galilaeus multifasciatus, S. melanotheron* and *T. zillii* in the southern and western rivers. Two other commercially important species, *T. discolor* and *S. galilaeus multifasciatus* occur in Ghana's only natural lake, Lake Bosumtwi (Whyte 1975).

O. niloticus occurs in the Bia River, but has not been encountered in any of the other southern and western rivers. The results of a recent electrofishing expedition (February 1987) to some of the southern rivers (Praa, Birim and Ofin) confirm this (J.K. Ofori, unpublished data).

The formation of the Volta Lake in 1965 provided a large waterbody in which tilapia species, including *O. niloticus*, proliferated, especially in the southern section. In experimental catches taken in October-November 1965, tilapias made up over 60% of the total. Large populations developed in the Afram arm and the areas below Kpandu (Petr 1969). In 1981, a second dam, the Kpong, was completed on the lower Volta below Akosombo and the reservoir created now supports an important tilapia fishery, mainly *O. niloticus* (Dankwah 1984).

With the realization that endemic Ghanaian tilapia populations may become mixed with introduced strains and species, the separation of the Volta basin from the southern and western rivers is very important. Introductions and transfers of exotic species and strains, especially of *O. niloticus*, are more likely to be done in the south where most ponds are located. Escapees from this area would not have natural access to the Volta system.

The *O. niloticus* cultured in northern Ghana are probably derived from stocks in Burkina Faso, northeastern Côte d'Ivoire, or other rivers to the north and these can gain access to the Volta Lake. Unless these fish were obtained from sources outside the Volta system the effects of them mixing with other Volta fish may not be serious. However, it is possible that within the Volta system, including the lake, there are populations of *O. niloticus* with different characteristics. The lake is large and has numerous tributaries originating in three countries: the river Oti from Togo; the Red Volta and White Volta from Burkina Faso and the Black Volta

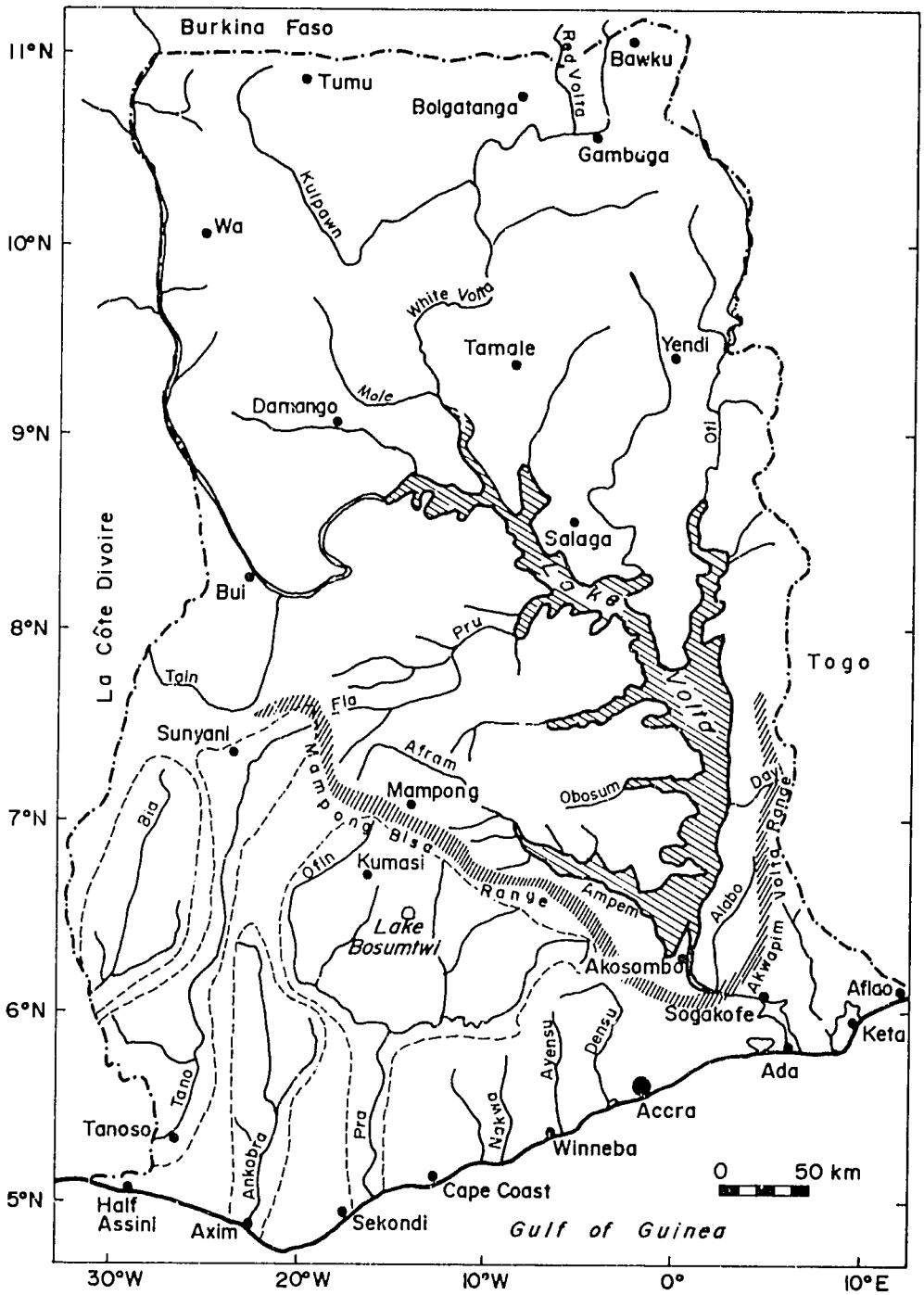

Fig. 18. Drainage systems of Ghana.

from both Burkina Faso and Côte d'Ivoire. It would be unfortunate if different strains were mixed because of further transfers and escapes.

The Volta Lake *O. niloticus* are regarded as good fish for both inland fisheries and aquaculture. Although regulations governing fish introductions exist, ineffective monitoring makes nonsense of those laws. Introductions are sought by fish farmers to satisfy seed requirements and to provide fish with better performance (although there is no evidence to support this concept). In a country like Ghana, where there are no large hatcheries and little or no information on the importance of tilapia genetic resources, conservation of the seemingly uncontaminated natural stocks would benefit from the following:

1. Discouraging introductions of other exotic tilapia strains or species into Ghana. This could be done by setting up hatcheries to supply Ghanaian tilapia seed to farmers and by effective demonstrations and training for farmers.
2. Support for further research and training of research and extension staff through collaborative programs. This would enable local researchers and extension officers to solve the problems associated with tilapia culture.
3. Research to improve the culture performance of Ghanaian tilapias and to encourage their use rather than the introductions of new strains and species.
4. Further documentation of the different strains of *O. niloticus* in the Volta Lake or associated rivers and designation of conservation areas to preserve important stocks. Such areas may be found in the National Game Reserve Parks in northern Ghana where there are pools and rivers connected with the Volta system. Large dams in northern Ghana and in the south could also possibly be used for this purpose.

Tilapia Culture in Ghana

There is little tradition of fish culture in Ghana. It began in the early 1950s with the stocking of dams in the northern region. The origin of the fish used is not recorded but they were almost certainly *O. niloticus* from the Volta system. The Department of Fisheries obtained tilapia stocks from the wild. These dams were really extensive fish farms.

In the 1960s, interest in fish culture took second place to interest in the creation of the Volta Lake and its fisheries. In the late 1970s interest in aquaculture was rekindled. However, in 1982-1983 aquaculture in Ghana suffered a great setback. The drought destroyed many farms. A lot had been very badly sited.

Four species (*O. niloticus, S. galilaeus, S. melanotheron* and *T. zillii*) have all been cultured to various extents. Very often two or three species are cultured together, especially in ponds in the southern part of the country. All the stocks cultured here have come from Ghanaian waters, such as the Volta around Akosombo, or have been exchanged between farmers. No exotic strains or species have been imported. Yields are very variable (2-5 t/ha/year). Feed supply is a major problem. High grade feeds are usually given to livestock rather than fish. Thus there is now a research program on cheap effective feeds for fish.

In and around the city of Kumasi, there is culture of *T. busumana*. Its growth performance is still under investigation.

The new station of the Institute of Aquatic Biology at Akosombo (now under construction) will provide facilities for more comparative evaluation of the culture performance of Ghanaian tilapias under different culture conditions. Research on the population genetics of Lake Volta fishes, including tilapias, is being pursued by a member of the IAB staff, Mr. E.K. Abban, in cooperation with the Department of Genetics, University College of South Wales, Swansea, UK.

Discussion

Dr. Pullin asked for confirmation that west of the Volta there are no native *O. niloticus* in any southern flowing rivers in Ghana and Côte d'Ivoire.

This was confirmed.

Dr. Pullin also asked whether tilapias from Côte d'Ivoire could gain access via brackishwater in the lower Tano up to the Ghanaian portion of the river.

Mr. Ofori reported that collections on the Tano to date had not turned up any *O. niloticus*.

Dr. Payne commented that temperatures in the north of Ghana and Côte d'Ivoire can be very low, especially when the Harmattan is blowing. These areas could be a source of cold-tolerant strains. *O. niloticus* introduced from Burkina Faso into ponds at Tono, north Ghana had mature gonads and fry production was observed during a prolonged period at 16-19°C.

Dr. Thys van den Audenaerde recalled fishing in Lake Volta close to Ampem about three years after the formation of the lake in an area from which the forest had not been cleared prior to inundation. There was a tremendous quantity of decomposing organic material at about 15 m depth. Fishermen brought up good catches of large tilapia which survived for over 24 hours in water almost devoid of oxygen. He added that in relation to the presence of *O. niloticus* in the Bia River, it was introduced to the dam at Ayamé, Côte d'Ivoire over 25 years ago by the CTFT. From here it certainly spread upstream. Therefore the Bia *O. niloticus* is this introduced strain stocked from Bouaké and derived originally from Burkina Faso.

Mr. Ofori agreed with this and also drew attention to the *O. niloticus* farms close to the Bia in Côte d'Ivoire and the likelihood of escapes. The fish here also came from Bouaké.

Mr. Nugent confirmed that the Ayamé dam on the Ivorian section of the Bia was stocked a long time ago with introduced *O. niloticus*. Indeed all the *O. niloticus* used for culture and stocking purposes in Côte d'Ivoire are derived from introductions. He also confirmed the presence of numerous fishponds along the Bia, some close to the Ghanaian border and some actually over the border. There are also fishponds in the north of Côte d'Ivoire close to the Ghanaian border. These have developed in the last few years and the farmers use the 'domesticated' 'Ivory Coast strain' of *O. niloticus* from Bouaké [see p. 22-24 and 25-26 for the history of this strain, Editor]. The same strain is used in farms in the far northeast of Côte d'Ivoire, both in ponds and cages, in an area which is part of the Niger catchment. *O. niloticus* is native to Côte d'Ivoire in only a few northern flowing streams of the Bagoue River flowing towards Mali and a few small streams belonging to the Volta system (Daget and Iltis 1965).

Dr. E. Trewavas contributed the following additional information. *S. galilaeus multifasciatus* is a subspecies found in Lake Bosumtwi, the Tano River and southern rivers of Cote d'Ivoire (Daget and Iltis 1965; Trewavas 1983). *T. busamana* is found in Lake Bosumtwi and the rivers Pra and Tano. *O. niloticus* does not occur naturally in these rivers. The Volta population of *O. niloticus* should now be thoroughly checked to make sure that *O. aureus* is absent.

Madagascar
Dr. J. Moreau

Tilapiine fishes (*Tilapia, Oreochromis* and *Sarotherodon*) are not native to Madagascar. They were introduced mainly during the 1950s towards the end of the colonial period. The first introduction was of *T. rendalli* in 1951 from the Djoumouna Fish Culture Center in Brazzaville, formerly in the French Congo. The aims were to improve fish culture because of expected great potential for tilapia production, and to fill apparently vacant ecological niches in lakes (mainly at high altitude) because of the relatively poor diversity of the native fish fauna.

Information on tilapia introductions was obtained from a number of sources, including some French Forestry Officers who worked in Madagascar during the relevant period (Moreau 1986). Fish were usually flown in and acclimatized at the Sisaony Fish Culture Center close to Antananarivo (Fig. 19). Usually 200 to 300 survived as far as the airport. They were often kept overnight in the French Fishery Officer's bathroom and about 50% usually survived to form the founder populations at the center. From the center's stocks progeny were distributed to other governmental fish culture centers mainly: Ambatofotsy close to the city of Ambatolampy; Perinet/Analamazotra near Moramanga; Ampamaherana near Fianarantsoa; Ivoloina near Toamasina (formerly Tamatave) and Ivakoina near Manakara.

Tilapias were also stocked in natural waters. [For example, Lake Itasy, was stocked with *T. rendalli* in 1955; *O. macrochir* in 1958 and *O. mossambicus, O. niloticus* and *T. zillii* in 1961-1962 (M.M.J. Vincke, pers. comm. to Editor)]. Some unintentional introductions happened when fish culture centers were flooded during cyclones. In the fish culture centers, the separate maintenance and quality control of each strain was very strict during the colonial period. After independence, this standard was maintained at the two research stations receiving assistance from the French Centre Technique Forestier Tropical (CTFT): Analamazotra and Ampamaherana. Here, even after a cyclone, each strain was checked and put in separate ponds.

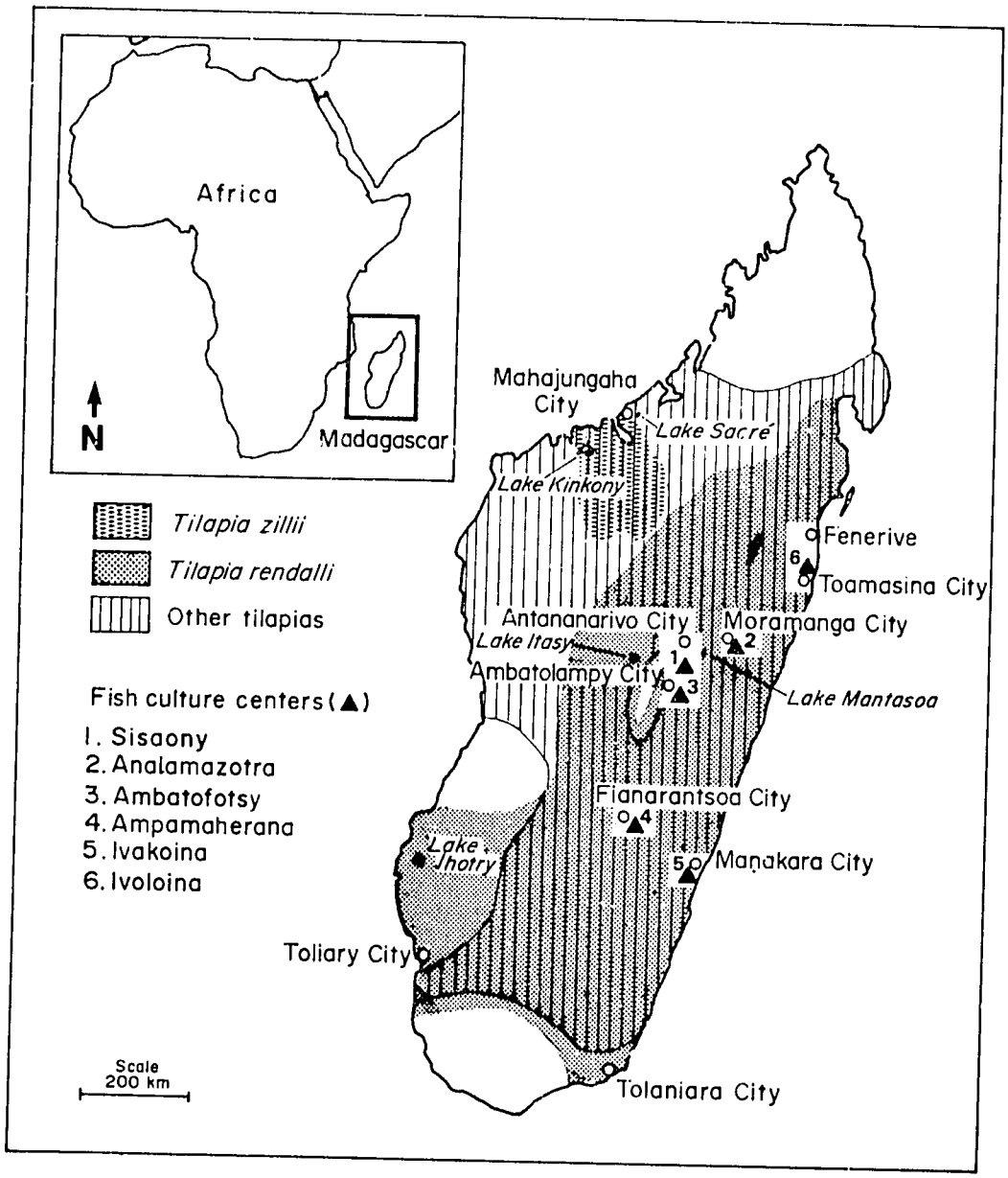

Fig. 19. Distribution of tilapias in Madagascar.

Any fish of dubious identity were given as food to station workers. This procedure was followed by A. Kiener, Y. Thérézien, M.M.J Vincke and P. Morissens, who left Madagascar in 1976. At present, the status of tilapia strains in these two fish culture centers is unknown. The government's main current interest is carp production in the highlands.

The introduced strain of *O. macrochir* is the same as that referred to by Dr. Thys van den Audenaerde (p. 5) as the Mweru strain. It was introduced in 1955 from the Djoumouna Center. [The founder stocks of the Djoumouna Center came from the Parc Heenen Reproduction Centre, Lubumbashi, Zaire, and were therefore of Lake Mweru origin (M.J.J. Vincke, pers. comm. to Editor)]. It has been an important species in open water fisheries at all altitudes. It is doubtful, however, whether pure *O. macrochir* can still be found in Madagascar. For example, there has been introgressive hybridization between *O. macrochir* and introduced *O. niloticus* (Vincke 1971; Daget and Moreau 1981; Matthes 1985) and probably other species like *O. mossambicus*. This is not surprising because often several species were introduced to the same waterbody and further unintentional introductions occurred during floods. Usually *O. niloticus* became dominant.

According to the files of the French Administration, *O. niloticus* was introduced from the Nile in Egypt in 1956 [and from Mauritius in the same year, (M.M.J. Vincke, pers. comm. to Editor)]. Several drainage basins now contain *Oreochromis* hybrids. Transfers of *O. niloticus* to Lake Mantasoa from the Analamazotra Fish Culture Center were performed by M.M.J. Vincke in 1970, 1971 and 1972. Here *O. niloticus* may have remained a pure species and seems rather cold-tolerant. Pure *O. niloticus* probably still exists in some natural waters because of ecological barriers and the lack of further introductions or transfers of tilapias since mid-1972. [The last transfers of *O. niloticus* to Lake Mantasoa were in 1972 and other transfers of *O. niloticus* were made from the Périnet-Analamazotra Fish Culture Center to the artificial Lake Tsiazompaniry in 1971-1972 (M.M.J. Vincke, pers. comm. to Editor)].

T. rendalli exhibits great cold tolerance in Madagascar (surviving down to 8-10°C) and is the only *Tilapia* for which reproduction has been recorded in natural waters above 1,600 m (Kiener 1963). It can still be found as a pure species in high altitude lakes in Madagascar. [The population in the artifical Lake Tsiazompaniry should still be pure (M.M.J. Vincke, pers. comm. to Editor)]. It also exhibits exceptional salt-tolerance (almost up to full strength seawater) in the Ihotry Lake near Toliary in southwest Madagascar. [See comments by Thys van den Audenaerde on tolerance of tilapias to environments very different from those of their natural range, p. 10, *T. rendalli* is a freshwater form - Editor]. It remains the most widespread tilapia in Madagascar and can still be found as a pure species in this lake.

T. zillii was introduced in 1955 from Nairobi and was widely distributed from a founder population of 200 fish which survived at the first recipient Fish Culture Station. It is now abundant in the basin of Lake Kinkony, in which *T. rendalli* has also been recorded (Thérézien et al. 1967).

O. mossambicus was introduced in 1956 from Mauritius and Mozambique for rice-fish culture. It was formerly abundant in most places mainly at lower altitudes and in brackishwater areas but we cannot tell its present status because of the possibilities of hybridization with other *Oreochromis* species. In 1972, a small population of *O. mossambicus* was recorded in an isolated small body of clear water locally called "Lac sacré" near the Mahajungaha airport. About 200 fishes of mixed sizes were seen living there, coexisting with introduced *Heterotis niloticus*. Because of its isolation and the poor road access this strain has probably remained uncontaminated.

Six juvenile *O. shiranus* were introduced to the Périnet Analamazotra Fish Culture Center from Malawi in 1969. They bred three times up to March 1970 but not thereafter. [The stock at the Center was destroyed in 1972 because it was considered slow-growing (M.M.J. Vincke, pers. comm. to Editor)].

O. spilurus niger (T. nigra) was introduced from Kenya in 1955 (Kiener 1963). [This species can still be found in some rice fields around Antsirabé; (M.M.J. Vincke, pers. comm. to Editor)].

No current data can be provided on tilapia open water fisheries in Madagascar, but in 1977-1980 they contributed about 20,000 t/year: 60 to 80% of catches. It is difficult to give any reliable figures for tilapia culture production.

Discussion

Dr. Coche said that the most important species for aquaculture in Madagascar is now the common carp, *Cyprinus carpio*, which is being used extensively on the upper plateau. Interest in tilapia culture is low but an FAO project plans to use tilapia in future aquaculture projects at lower altitudes. The species used will probably be *O. niloticus*. In recent years, there have been several severe cyclones in Madagascar and some Fish Culture Centers have been destroyed. The station that Dr. Moreau mentioned at Ivakoina was completely inundated, so all the tilapias that it was holding have spread to the wild. [They have spread in the Pangalanes; coastal lagoons south of Toamasina (Tamatave) (M.M.J. Vincke, pers. comm. to Editor)].

Dr. Pullin invited Dr. Moreau to comment further on the 'tilapia trois-quarts' (three-quarters tilapia) as one of the best documented examples of tilapia hybridization in natural waters.

Dr. Moreau explained that the fish was given this name by the fishermen of Lake Itasy. In 1966, the lake produced only *O. macrocnir*. Then the 'tilapia trois-quarts' began to appear in catches and also some very fine, fast growing *O. niloticus* were seen. The situation was investigated and recognized as a typical case of introgressive hybridization.

['Tilapia trois-quarts' was first discovered by Vincke in July 1968 while experimental fishing in Lake Itasy (Vincke 1971). Note that this recognition of the hybrid came years after the introductions to Lake Itasy (see p. 30). Hybridization therefore took a long time - Editor.]

Dr. Moreau said that by 1976, when he was last in Madagascar, fish that resembled pure *O. niloticus* were rare in Lake Itasy. This course of events and the consequent reduction in the fish yields from the lake (from 320 to 80 kg/ha) over the ten-year period have been described by Daget and Moreau (1981).

The following table was later sent by M.M.J. Vincke to illustrate the relative catches of *O. niloticus* and 'tilapia trois-quarts'.

Table 3. Lake Itasy, Madagascar: catch composition (as % in number) between *Oreochromis niloticus* and 'tilapia trois-quarts', from published sources 1964-1985 (compiled by M.M.J. Vincke).

Species	*Oreochromis niloticus*	Tilapia 'trois-quarts'
% in number in 1985 Matthes (1985)	57%	38%
in 1976 Moreau (1979a)	40	56.2
in 1970 Vincke (1971)	5.55	91.69
in 1963-64 Thérézien (1964)	0.06	0

Malaŵi

Mr. O.V. Msiska

Tilapias present in Malaŵi

There are many indigenous cichlid species, including tilapias, in Malaŵi. *Oreochromis niloticus* has not been introduced. Introductions of exotic fishes are not allowed because they could threaten the survival of native species and the ecology and fisheries of Lake Malaŵi.

The most important tilapias fished in Lake Malaŵi are the 'tasselled' species: *O. squamipinnis, O. sakus, O. lidole* and *O. karongae* (Fig. 20). These form a large fishery in Lake Malaŵi. The current yield of tilapias from the lake is about 20,000 t/year out of a total of 60,000-70,000 t/year. These tilapias are found only in Lake Malaŵi. They normally mature and breed at a large size (240-285 mm total length). This is a larger size at maturity than say *O. niloticus* and these species could be candidates for aquaculture. They do not breed at depths of less than 5 m but could be particularly useful for fish production from farm dams with deep portions.

Malaŵi also has the following species: *O. shiranus shiranus; O. shiranus chilwae; O. placidus; O. mossambicus* and *Tilapia rendalli*. *O. shiranus chilwae* is confined to Lake Chilwa which has a history of drying-up about every six years or so. When the lake is refilled it is recolonized from residual populations in feeder streams. *O. shiranus shiranus* and *T. rendalli* occur in the marginal areas, swamps and rivers draining into the lake. *O. mossambicus* and *O. placidus* are restricted to the southern part of the country. They are found in the areas that form part of the Zambezi drainage basin.

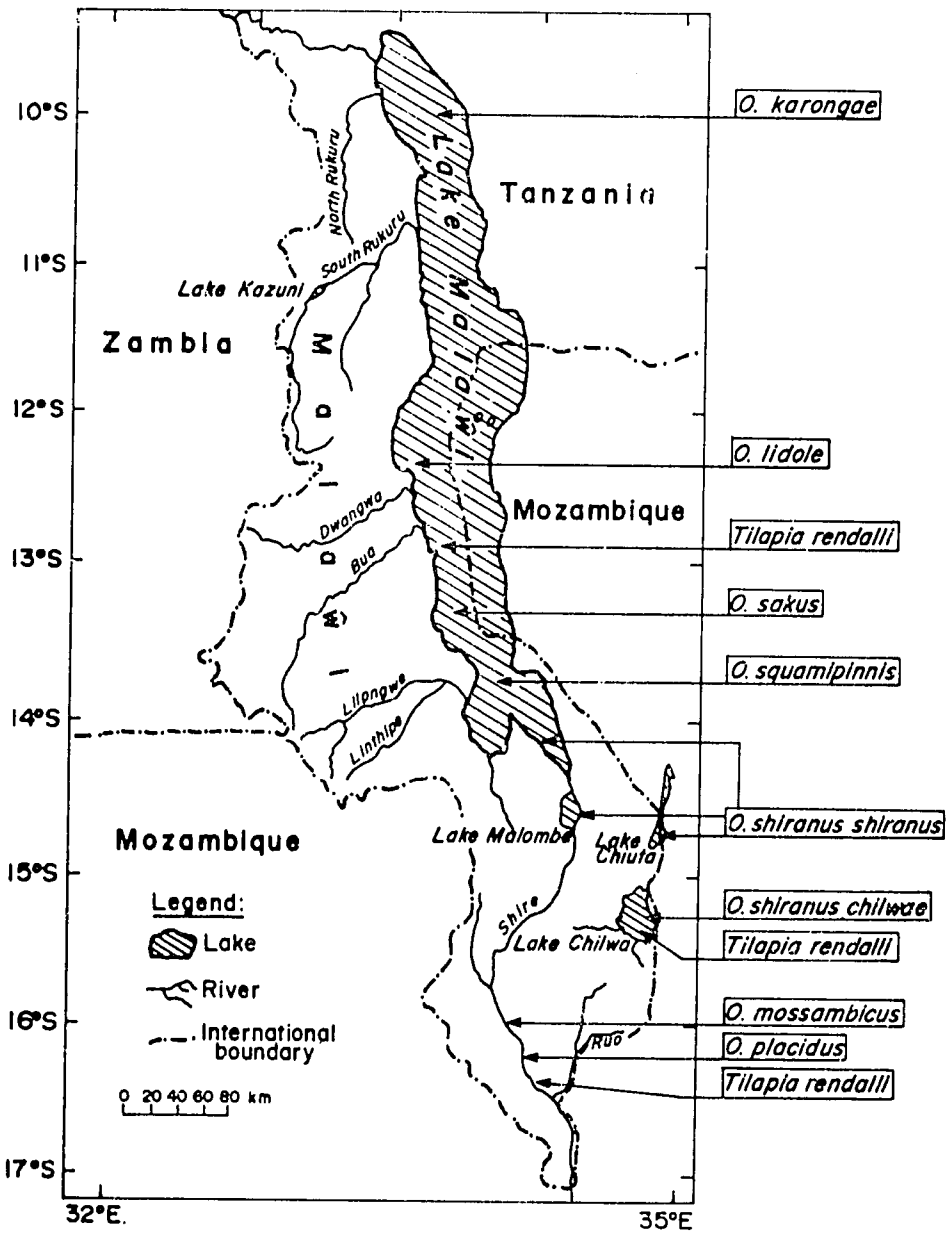

Fig. 20. Major waterbodies and watercourses of Malaŵi with an indication of the distribution of tilapias.

Culture performance

O. shiranus shiranus appears to have better pond culture characteristics than the other species available. However, comparative trials with *O. sh. shiranus* and *O. mossambicus* are continuing. [Vincke (1981) describes *O. sh. shiranus* and *O. sh. chilwae* as slow-growing in ponds; at best 0.25 g/day with feeds and fertilization. More recent studies show that 1 g/day is possible with *O. sh. chilwae* (O.V. Msiska, unpublished results) - Editor]. The usual pond culture practice in Malawi is to stock a mixture of *T. rendalli* with one or more *Oreochromis* spp., i.e., a polyculture.

In the hottest areas of Malawi (100-200 m elevation) *O. mossambicus* can outperform *T rendalli* when inorganic fertilizers (mainly phosphates) and rice bran are used as pond inputs. However, in ponds operated by the Sugar Company of Malawi in the same region (Lower Shire), receiving inputs from the sugar mill (bagasse and molasses), rice bran, urea, superphosphate and lime, *T. rendalli* outperformed *O. mossambicus* (Allsop 1986; N. Commins, pers. comm.). Therefore it is important to match the feeds and other inputs used to the feeding preferences of the species. Current yields from pond culture of tilapias in southern Malawi range from 0.5 to 4.6 t/ha/year (Cross 1985; Msiska and Nongwa 1985).

T. rendalli performs better at higher altitudes (around 1,000 m; 22°C) than any *Oreochromis* spp. available in the country. More research is needed on the relative merits of different species under different culture conditions in these higher, cooler areas, which cover much of the country. These are the areas farthest away from the fisheries of Lake Malawi and therefore most needy in terms of fish supply. Hence the need for aquaculture development.

It follows that cold-tolerance is an important trait for tilapias cultured in most of Malawi, as indeed it is for tilapia culture in much of Africa. Although *O. mossambicus* is reputed to be a cold-tolerant species, the stocks present in Malawi have performed poorly in the higher, cooler areas.

O. placidus may be a better fish for culture in ponds than *O. mossambicus*. It breeds easily in ponds. It has a smaller head than *O. mossambicus*: therefore its dress-out percentage is better.

It is hoped that a polyculture of suitable species will minimize the problem of supplying inputs into ponds as farmers in Malawi generally have limited resources.

Discussion

Dr. Guerrero asked whether the four lacustrine species that do not breed at less than 5 m depth in Lake Malawi have been bred in pond culture.

Mr. Msiska replied that trials have been done in two dams (5-7 m deep) with what was probably *O. squamipinnis* (the juvenile stages of the lake species look very similar and they are very difficult to separate by superficial examination, unless in breeding coloration). The fish bred there. This species has been introduced to ponds but this was not successful. There is little or no reproduction in ponds.

Dr. Lowe-McConnell enquired whether the fish had distinct breeding seasons in the dams and remarked that the four species all have distinct breeding seasons in Lake Malawi.

Mr. Msiska said that in one dam, *O. squamipinnis* had a distinct breeding season over a two-year period of observation.

Dr. Pullin asked whether these species matured in ponds, but just did not spawn.

Mr. Msiska replied that this was so; fish that have been dissected have mature gonads but generally do not spawn in ponds.

It was confirmed by Drs. Lowe-McConnell and Thys van den Audenaerde that *T. rendalli* is native to Malawi and is not an introduced species. Its native distribution, however, is restricted to marginal lagoons and waters around Lake Malawi.

Dr. Coche raised the issue of conservation of the ecosystems of Lake Malawi and pointed out that its shores extended to countries other than Malawi. He reported that *O. niloticus* has been introduced by private farmers in Tanzania not far from Lake Malawi, assisted by American missionaries.

The origin of these fish was not known to anyone present at the workshop. It is feared that escapees may reach Lake Malawi.

Zimbabwe
Dr. B. Marshall

The natural distribution of tilapias in Zimbabwe

Zimbabwe has no large natural lakes, floodplains or perennial rivers (apart from the Zambezi). Prior to European settlement of the country, the majority of the rivers probably contained very few tilapias. Even today, the fish fauna of undammed rivers is dominated by cyprinids and other families. However, many thousands of dams have been built since the idea was first introduced in 1902 and dams now form an important tilapia habitat. Many of the dams were stocked originally for angling purposes.

Tilapia rendalli and *T. sparrmanii* are native to Zimbabwe. The original natural distribution of *T. rendalli* is not known but it is now widespread. It has been distributed to clear vegetation in dams stocked for angling. *T. sparrmanii* prefers waters with aquatic vegetation and the widespread distribution of *T. rendalli* has reduced *T. sparrmanii* populations and had deleterious effects on other species as well (Junor 1969).

There are five *Oreochromis* spp. (Fig. 21). The country is bordered by the Zambezi River in the north and the Limpopo in the south. These rivers drain east to the Indian Ocean. There is another major drainage system, the Save, which leaves the country in the southeastern corner and also drains to the Indian Ocean via Mozambique. A further system drains west into the Makgadikgadi salt pans in Botswana. There are no fish in the Kalahari sand areas of the northwest with seasonal pools, but no rivers.

There is a central watershed running east-west. Rivers to the north drain to the Zambezi and those to the south to the Limpopo or Save. The Victoria Falls mark the boundary of the Upper and Middle Zambezi. West of these falls, *O. macrochir* and *O. andersonii* are found. The Middle Zambezi (from Victoria Falls to the Cabora Bassa gorge) is naturally a fast river flowing through gorges; very different from the Upper Zambezi (a flood plain river with marshy banks). In the Middle Zambezi one finds *O. mortimeri*. A similar situation is found on the Kafue - the major tributary from Zambia, i.e., *O. macrochir* and *O. andersonii* above the Kafue falls and *O. mortimeri* in the gorge below. It is assumed that all the rivers draining in the Zambezi, i.e., those north of the watershed, contain *O. mortimeri*. South of the watershed, there is *O. mossambicus* and *O. placidus* comes up the Save system as far as two waterfalls on the two major rivers that form the system (Bell-Cross 1972, 1976; Minshull 1987).

Introductions

There have been many undocumented introductions of tilapias to Zimbabwe. For example, *O. andersonii* was introduced in the 1950s, but no one had details of the introduction. It may have become mixed in with many populations of *O. mortimeri* and *O. mossambicus*. The descendants of the introductions have vanished (Jubb 1974; Toots 1969).

Lake Kariba was filled by 1963. It was assumed that it would support very few tilapia because very few had been caught in the pre-impoundment surveys on the river. However, as soon as the lake was filled, *O. mortimeri* flourished - breeding prolifically and growing to large sizes. Again, because of the poor tilapia catches in pre-impoundment surveys, an introduction was made of fish from the Chilanga Fish Culture Station, Zambia (the 'Chilanga cocktail'). These were intended to be *O. macrochir* on the premise that this species is lacustrine in Lake Mweru and would do well in Lake Kariba. It is not known why no attempt was made to import from Lake Mweru directly. The introduction contained, in addition to *O. macrochir*, *O. andersonii* and many other cichlids (haplochromines, *Serranochromis* spp., etc.). *O. andersonii* from the Kafue River has also been used in farm dams with drainage into Lake Kariba from the north.

Therefore the lake now has a whole host of introduced species. *O. macrochir* is rarely caught in the lake. Very large fish that are neither *O. mortimeri* nor *O. macrochir* are occasionally taken by fishermen. These are possibly hybrids. Unfortunately good specimens are lacking.

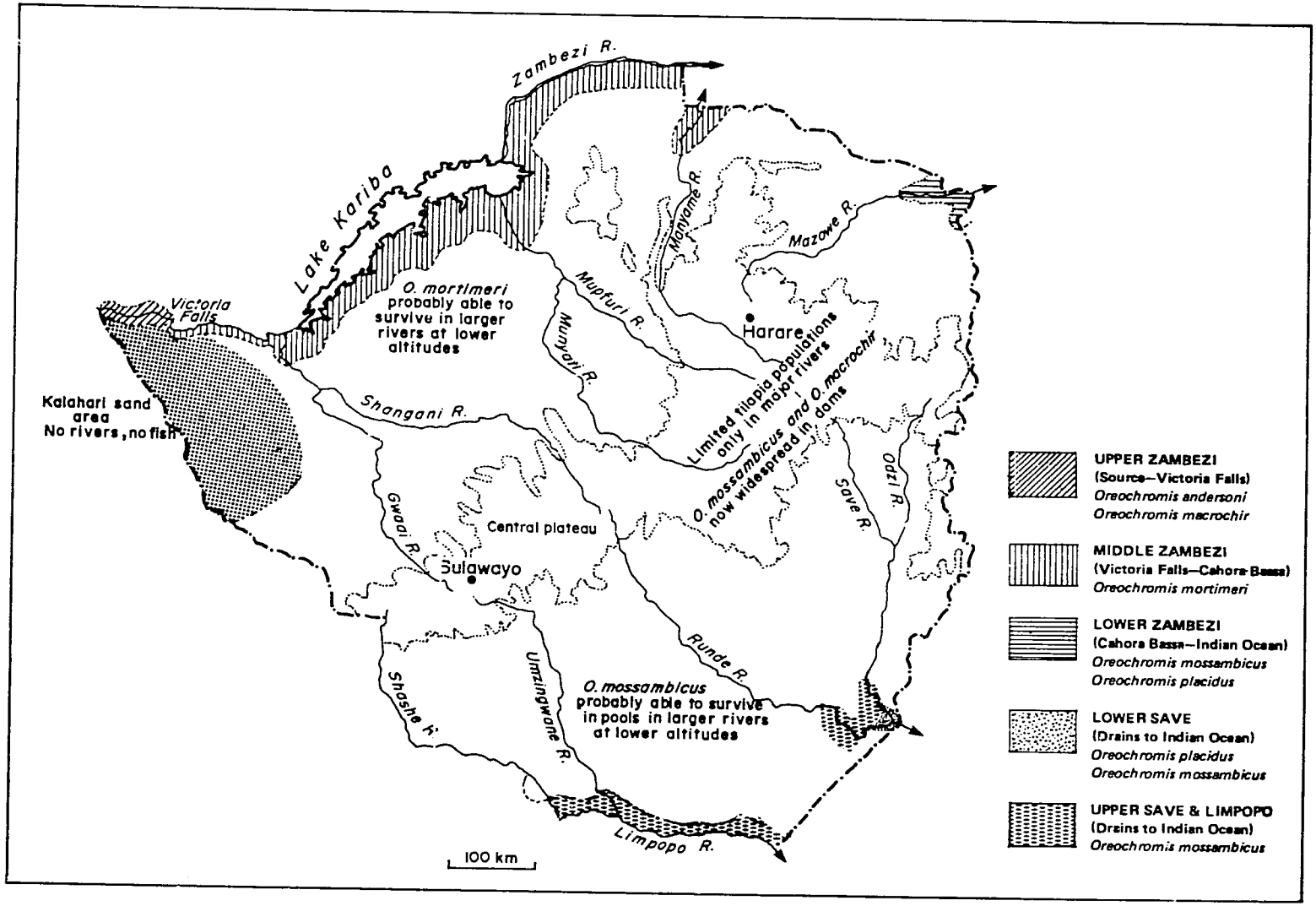

Fig. 21. The probable natural distribution of *Oreochromis* spp. in Zimbabwe.

Further introductions of *O. macrochir* from the Kafue River have been made chiefly in the northeast of Zimbabwe for stocking dams and reservoirs. It has displaced *O. mortimeri* and *O. mossambicus* (wherever it formerly occurred), except where there is abundant vegetation. In the eastern mountains *O. macrochir* was introduced accidentally into a dam used for trout fishing. It survives here, although a lot die off in winter, and it is sometimes caught on trout flies. This displeases the trout fishermen!

The picture in Zimbabwe is one of widespread uncontrolled and undocumented introductions, transfers and mixing. There is a dam on the Save system (Lake Kyle) that formerly had a native population of *O. mossambicus*, but *O. macrochir* and *O. placidus* have now been introduced and hybridization may have occurred. This could threaten the genetic purity of populations lower down the Save system, particularly the native populations of *O. placidus*. Finally, commercial aquaculturists are now planning to introduce *O. niloticus* and *O. aureus*.

Current status of aquaculture

At present there is very little tilapia culture in Zimbabwe. The main reasons are probably water shortages throughout much of the country and (until fairly recently) an abundance of relatively cheap red meat. Local species have been used for culture in a rather haphazard fashion and the results have been discouraging to date: hence, the recent push to introduce *O. niloticus* and *O. aureus*. The local species have probably not been given a fair trial in well-managed aquaculture. They should be re-evaluated.

Discussion

Dr. Pullin asked for clarification on the introductions of *O. niloticus* and *O. aureus*. Have introductions actually been made yet? If so, where did the fish come from?

Dr. Marshall said that small introductions have been made by private farmers. They are thought to have come from Israel. They are not used in production yet. Such introductions do not contravene any of the laws of Zimbabwe.

Dr. Hulata asked from which hatchery in Israel the fish were obtained.

[Mr. J.D. Balarin later supplied the following information (Table 4) - Editor].

Table 4. Introductions of *Oreochromis aureus* and *O. niloticus* to Zimbabwe by commercial fish farmers (1983-1987).

Location of importing farm	Species	Source	Year	Remarks
Lake Darwendale	*O. niloticus* + *O. aureus*	Ein Hami-fratz Israel	1983-84	Farm now sells hybrids
Lake Kariba	*O. niloticus*	Nakambala Estates farm, Zambia	1985	Fry distri-buted in Zimbabwe
Lake McIlwaine	*O. niloticus* + *O. aureus*	Baobab Farm Kenya	1986	Imported 1,000 *O. niloticus* and 'a few' *O. aureus*
'Arcturus'	*O. niloticus*	Stirling University UK	1987	-
Chegutu	*O. niloticus*	Baobab Farm Kenya	1987	Imported 3,000; 500 selected for breeding

Further Discussion on African Tilapia Genetic Resources

Dr. Pullin read the following comments sent by Dr. E. Trewavas, British Museum (Natural History).

Oreochromis schwebischi is abundant in the lagoons of the lower Ogowé River, Gabon, and supports a good fishery there. There is considerable information on this species under its synonym *T. flavomarginata* in Thys van den Audenaerde (1964) and Loubens (1965) and also in Trewavas (1983). In the same lagoons, the Congo estuary and the Lower Bengo and Quanza rivers of Angola, there is the substrate spawner *T. cabrae*: synonym *T. haugi* (Loubens 1965). *T. cabrae* is a fine deep-bodied fish, similar in appearance to *T. rendalli*. It feeds on a mixed diet of filamentous algae and other fragments. According to Dr. Machado, formerly of the Dundo Museum, Angola, *T. cabrae* is much preferred to the local mouth brooder *O. angolensis* as a food-fish. *O. schwebischi* and *T. cabrae* might have potential for aquaculture.

Regarding *O. schwebischi*, Dr. Thys van den Audenaerde reported that it is found in the upper Ogowé River up to near Franceville and in all associated rivers up to just north of the Zaïre River. It is a microphagous species and probably takes many types of food. Very old specimens develop monocuspid teeth, resembling those of *O. mossambicus*. It was tried in fishponds close to Libreville in 1966. The people responsible for these trials said that it gave inferior results to those achieved with *O. macrochir*. However, it is doubtful that the trials were conclusive. Anyway, culture of *O. schwebischi* was abandoned.

Dr. Thys van den Audenaerde said that *T. cabrae* is a very 'high-backed' species and should have a good meat yield as a cultured fish. However, it belongs to the same group as *T. brevimanus* and *T. mariae*. This group do well as aquarium fish, but their gill rakers and teeth are not like those of the more omnivorous species that do well in aquaculture. This group (not *T. brevimanus*) feed on worms and insects. *T. cabrae* has never been tried in fish culture. It is found on the lower Gabon River from the coast up to the falls at Lambaréne (but not above) and in similar coastal rivers down to Angola. It avoids fast-flowing waters. *T. mariae* is a similar species found in lower Nigeria. Again it has not been tried in ponds. It is doubtful that these rather specialized 'carnivorous' species would be useful for fish culture - at least for fish culture involving fertilization of the water to produce plankton and other natural feeds used by the more generalist microphagous tilapias.

Dr. Pullin asked whether there are any other species that have the good combination of gill rakers and pharyngeal teeth that gives *O. niloticus* and *O. aureus* such feeding versatility.

Dr. Thys van den Audenaerde replied that from his experience so far, which spans about 40 years, the microphagous female mouth brooders (*O. aureus*, *O. niloticus* and possibly *O. mossambicus*, *O. macrochir* and others) appear to be the best for pond culture. There may be good reasons for culturing other species under certain local conditions, but certainly this group of tilapias appears to be the best for pond culture. Screening numerous other tilapias for culture potential would take a lot of time and would quite possibly be a waste of time.

Dr. Trewavas' comments included mention of lakes Kainji, Nasser and Turkana and freshwater lakes on the lower Sénégal River as possible localities for collecting pure strains of *O. niloticus* and *S. galilaeus*, but cautioned on the possibilities of 'new developments' affecting these populations.

Dr. Payne recognized the importance of *O. niloticus* for aquaculture, but recommended that other species be considered as well for selective breeding programs to support the long-term future of tilapia culture. For example, *O. aureus* exists as a fairly isolated population in the Nile Delta. This species has already been proved useful in aquaculture. However, its west African populations have never been investigated for culture potential. Also, *O. urolepis hornorum* from the Wami River system in Tanzania has been used in aquaculture. The next river system south is the huge Rufigi system, from which *O. urolepis hornorum* is absent: only *O. urolepis urolepis* is found here. As a subspecies closely related to *O. u. hornorum* it may well possess the some useful genetic properties for producing 100% male monosex progeny in certain hybrid crosses. Its population must be larger than that of *O. u. hornorum*. The value of these resources for future breeding programs is unknown.

In Sierra Leone, there is a series of small rivers (called the 'Atlantic Guinéen' by Daget). On one such river, the Taia River, six species of tilapias can be found along a fairly short freshwater

stretch: *T. joka, T. louka, T. brevimanus, T. buttikoferi, Sarotherodon occidentalis* and *S. caudomarginatus*. In the estuary are another two species: *T. guineensis* and *S. melanotheron*. The occurrence of so many species in such a small area is important not only for possible future use in aquaculture but also for future evolutionary studies on the tilapias. Perhaps this area of West Africa was in fact the 'cradle' of tilapia evolution. Whether it was or not, such resources should not be destroyed by ill-considered introductions and transfers.

Dr. Payne further stressed the need for care and patience in identifying tilapias, particularly in the field. He stated that there are probably many undiscovered tilapia populations that have not yet been affected by hybridization with introduced species. It is important to train field workers to recognize different tilapia species.

Dr. Hulata stated that *O. aureus* is an important species in Israel for aquaculture. However there is no undisturbed native Israeli population of *O. aureus* any more. Israel may wish at some time to introduce new genetic material of *O. aureus*. Therefore investigations on the West African populations would be very welcome.

Dr. Guerrero called for international cooperation and action to conserve important wild tilapia genetic resources from any further effects of human intervention. This should include herbivorous species and other species of possible aquaculture potential, not just *O. niloticus*.

It was agreed that there is a potential for conflict here between would-be aquaculture developers and conservationists. Dr. Trewavas has called this a conflict between the interests of zoogeographers and ecologists on the one hand and fisheries personnel on the other. Dr. Trewavas recommended that fisheries scientists be discouraged from embarking lightly on irreversible 'experiments'. Fish are sure to escape from ponds into local river systems and may oust or interbreed with local species. As a general rule, exotic species should not be introduced where good local species exist.

Dr. Lester said that a sense of proportion is required when considering introgressive hybridization. A few escapees from a fish farm into a major river system do not necessarily wreck the purity of the wild stocks. Introgression is usually a lengthy process. If the released population is very small compared to the wild population, then it will take a very long time for gene frequencies in the population to change much.

Dr. Pullin commented that we *should* be looking ahead for a very long time.

Dr. Lester agreed and explained that he was merely recommending that not all populations in natural waters be disregarded as useful genetic resources just because there had once been some aquaculture in the vicinity.

Dr. Payne said that introgressive hybridization is less likely in rivers than in standing waters.

Dr. Villwock said that introgression is a function of the ecological suitability of the habitat for the introduced species. If highly suitable, the species could proliferate rapidly and rapid introgression could ensue.

Dr. Pullin added that the only well-documented examples of introgression known to him were those of *O. macrochir* with *O. niloticus* (Daget and Moreau 1981) and *O. mossambicus* with *O. niloticus* in the Philippines (Taniguchi et al. 1985; Macaranas et al. 1986). He asked for other examples.

Dr. Moreau mentioned the natural hybrids between *O. spilurus niger* (*T. nigra*) and *O. leucostictus* (*T. leucosticta*) in Lake Naivasha (Elder et al. 1971). [Lake Naivasha formerly had no fish. Natural hybridization of tilapias has also occurred in Lake Kinkony, Madagascar, (M.M.J. Vincke, pers. comm. to Editor) and in Lake Victoria (Fryer and Iles 1972) - Editor].

Dr. Lester commented that the examples mentioned by Dr. Pullin (Madagascar and Philippines) are interesting because all the species involved are introduced - there is no native species involved.

Dr. Wohlfarth suggested that there may be a general rule as to whether hybridization will or will not occur. With two sympatric endemic species, there is no hybridization - otherwise the separate species would cease to exist. This is exemplified by the Nile stocks of *O. aureus* and *O. niloticus*. With introduced species, the picture is completely different.

Dr. Marshall commented on Dr. Payne's point about the reduced likelihood of hybridization in rivers and said that *replacement* of native species by introduced species was more likely in rivers. Replacement also occurs in lakes.

Dr. Lowe-McConnell stated that a major factor in replacement was competition for breeding grounds, not just competition for food.

Dr. Pullin posed the question, where are the best locations from which to collect pure species? and suggested that perhaps these are to be found in the parts of Africa where there has been little or no aquaculture.

Dr. Thys van den Audenaerde agreed that this is indeed the case and said that in West Africa this meant mainly the Sahelian countries. Here the fish supply comes only from river fisheries, because there is insufficient water for aquaculture. There are probably some very important undisturbed tilapia populations. However, the need to investigate these is urgent, because there are plans for future aquaculture development in Burkina Faso, Mali and possibly Sénégal. Such plans will require new water distribution systems and fish transfers. By contrast, Dr. Thys van den Audenaerde gave as an example the Logone River, which drains to Lake Chad. There is aquaculture close to the Logone in the Central African Republic and escapees of various species from farms may have reached the river and the whole Chad system. Its stocks may no longer be pure. Perhaps the least disturbed system of all is the Sénégal system. It should be possible to collect *O. niloticus* and *O. aureus* from some undisturbed West African populations.

[However, there has been a transfer of *O. niloticus* from Bouaké, Côte d'Ivoire, to the Richard Toll Station, which is on the edge of the Lac de Guiers expansion of the Sénégal River, Sénégal. The Sénégal River crosses Guinea, Mali, Mauritania and Sénégal. Aquaculture is practised in Guinea, Mali and Sénégal (M.M.J. Vincke, pers. comm. to Editor)].

Dr. Lowe-McConnell reported that Trewavas (1983) gives the natural West African distribution of *O. aureus* as the Sénégal River; the middle Niger as far south as Busa; upper tributaries of the Benoue River, Lake Chad and the lower Logone and Chari Rivers. She asked which of these populations should be regarded as possibly contaminated by other species?

Dr. Thys van den Audenaerde replied that the Sénégal stocks are almost certainly uncontaminated and the stocks in the Upper and Middle Niger are probably uncontaminated. However, the stocks in the Benoue system could be contaminated because there has been aquaculture development on the Jos plateau in Nigeria, which drains towards the Benoue. The Sénégal fish are the least likely to have been contaminated.

Dr. Villwock reported that *O. niloticus* is widespread in the Nile system and Lake Manzallah. A lot of new canals have been built between the Nile River and various oases in the delta and also down from the river to Lake Qarun and the Wadi el Ruwayan, south of the Oasis el Faiyum. Therefore, *O. niloticus* has spread throughout these systems. There has been a lot of hatchery breeding at Idfina in the western delta. As this area is in open contact with the canals, any strain with hatchery characteristics could spread throughout the system. Such releases from hatcheries should obviously be kept away from important undisturbed natural populations in the delta.

Dr. Payne commented that whereas it was formerly thought that *O. niloticus* and *O. aureus* would hybridize in Egyptian waters, in fact it is quite easy to collect and identify these separate species from Egyptian waters. They appear to act as 'good species' in Egypt and do not interbreed.

Dr. Smitherman drew attention to the good stocks of *O. aureus* still to be found in the Nile Delta. This northern population may have good cold tolerance.

Dr. Pullin said that it is a cause for concern that tilapias are being shipped into Africa for experimental or commercial purposes with little regard to the possible ecological consequences for natural populations. For example, shipments of *O. aureus* and *O. niloticus* have been made to private farms in Zambia and Zimbabwe and universities have shipped in fish for their own research and to assist development projects. Stirling University has shipped *O. niloticus* to Zimbabwe and Auburn University has shipped *O. niloticus* (of Egyptian origin) to Rwanda (a founder population of 22 females and 18 males in 1984). The practice of shipping small numbers of fish is widespread. For example, Auburn University received a founder population of four *O. aureus* (one female and three males) from Israel that subsequently produced 24,444 progeny. These *O. aureus* were the ancestors of the *O. aureus* transferred to Latin American countries by Auburn University. The Fish Culture Station at Bouaké, Côte d'Ivoire sent 60 juveniles each of *O. niloticus* and *'O. hornorum'* to the Experimental Fish Culture Unit of Pentecoste Ceara, Brazil, in 1971. There are two points to be made from all such examples.

1. Introductions to satisfy limited or short-term experimental/commercial objectives cannot be justified if they threaten the purity of important natural genetic resources.

2. Where introductions are justified, they must provide a broad genetic base so that inbreeding depression and genetic drift are avoided. To amplify this point, a contribution by Tave and Smitherman on effective breeding numbers is appended (Appendix II).

Mr. Balarin asked whether the consequences of introductions, transfers and interbreeding between exotic and native stocks is really a serious problem, because the genes? (for cold-tolerance, good growth, etc.) would surely still be there in the fish that survived?

Dr. Pullin responded that tilapia breeders in the future would need to take genes from wild types - as do plant breeders - therefore it is essential to conserve wild populations in an uncontaminated state. It would not pose a great threat to some tilapia genetic resources to introduce more exotic strains or species. For example, it could hardly be a threat of any consequence to introduce more strains (and therefore more genetic diversity) of *O. niloticus* to Côte d'Ivoire. However, the *undisturbed* wild stocks are potentially important genetic resources for future tilapia breeders *worldwide*.

Dr. Villwock agreed and said that for future breeding schemes to develop breeds for different environments, pure strains will be needed.

Dr. Lester added that introgressive hybridization that just allows exotic genes to spread within a natural population at a low freqency is not a serious problem. However, when two species become more completely mixed, it can be exceedingly difficult or impossible to extract the alleles needed for a given breeding objective. Crop breeders therefore tend to bank wild gene types for particular breeding objectives - especially disease resistance. One danger of a mixed population is that genes that had been fixed by selection due to a given environment at stress or disease may become very rare or lost because the introgressed population lives in a more benign (culture) environment.

Comparison with plants can be a little misleading, as many plants used in agriculture and horticulture are from inbred lines or are the result of many generations of artificial selection, hybridization etc. Tilapia breeding is a long way from this situation. Nevertheless natural genetic diversity from undisturbed wild populations is undoubtedly essential for future breeding work.

Dr. Pullin said that domestication and selection of crops and livestock has spanned thousands of years and that tilapia genetic diversity needs much more research to enable progress to be made in domestication and selection. Such efforts will be hindered if wild genetic resources are lost or irreversibly changed.

Mr. Balarin agreed but cautioned against trying to evaluate too many species and strains. The resources available for research will not allow this. Moreover, farming practices will change the genetic characteristics of farmed stocks; for example, partial harvesting of large fish and retention/breeding from smaller fish with subsequent distribution of the fry to other farmers.

It was agreed that this is a further reason for conservation of natural genetic resources: to be sources of new genetic diversity when farmed stocks deteriorate through such ill-judged breeding strategies or inbreeding.

Dr. Coche stressed that fish feeds are difficult to provide in Africa; therefore, tilapia culture in Africa is largely extensive or semi-intensive with the fish taking much of their nutritional requirements from natural foods. Integrated crop-livestock-fish systems or using composts as pond inputs are good examples.

Another considerable factor in Africa is cold temperature. For example, a recent projection of 600 t/year tilapia production from an aquaculture project in the Congo was shown to be nonsense because it had assumed 12 months production; the weather is too cold for tilapia growth and breeding at the place in question for five months of the year. In Kenya, *O. niloticus* grows well close to Lake Victoria, but above 1,500 m it performs very poorly due to the cold. In these situations, cold-tolerant strains or species are essential. In Kenya, use of additional exotic species on the lake catchment is discouraged because of the fear of undesirable ecological consequences. However, *T. sparrmanii* has been introduced and used for culture in cool areas. It is more cold-tolerant than *O. niloticus* although not really a good species for culture.

For saltwater culture, *O. spilurus spilurus* seems to be a good species to culture; certainly better than *O. mossambicus*. It has been used successfully in the Middle East: Kuwait (Hopkins et al. 1985) and Saudi Arabia. Dr. Coche recalled the remarks by Dr. Mark Caulton (see Pullin

and Lowe-McConnell 1982, p. 333-334) that *O. mossambicus* from the lower/middle Zambezi has a much better appearance than those *O. mossambicus* that have been spread throughout the world for culture purposes and that these southern African fish perform well in culture in South Africa. Perhaps there are some strains of *O. mossambicus* that are good for culture purposes? The population genetics of this species, as for all the tilapias, have hardly been studied at all. [For some information of the culture performance of *O. mossambicus* strains, see Lombard (1960). Clearly some strains of species perform better than other (M.M.J. Vincke, pers. comm. to Editor)].

Dr. Coche said that production of hybrid fry for culture purposes was generally not practical in rural Africa and that monoculture should probably be tried first rather than polyculture because supplying fry requirements of more than one species could also be problematical. He also said that it is extremely important that fry suppliers, which are mostly government stations in Africa, should keep their broodstock collections and fry production operations *well separated*, to guard against any more of the negative selection that has been prevalent for many years.

Asia

Philippines
Dr. R.D. Guerrero III
Mr. M.M. Tayamen

Tilapia culture in the Philippines started in 1950 with the introduction of *Oreochromis mossambicus* from Thailand. Three males and one female survived to form the founder population. Subsequent introductions have been of various strains of *O. aureus* and *O. niloticus* and one population of *Tilapia zillii* of unknown origin (Table 5).

Table 5. Tilapia introductions to the Philippines (1950-1982): modified from Guerrero (1985).

Species	Year	Origin	Agency
Oreochromis mossambicus	1950	Thailand	BFAR[a]
O. urolepis hornorum x O. mossambicus	1971	Singapore	Private sector
O. niloticus (Uganda)	1972	Israel	LLDA[b]
O. niloticus (Egypt)	1972	Thailand	BFAR
Tilapia zillii	1973	Taiwan(?)	?
O. aureus	1977	USA	CLSU[c]
O. niloticus (Ghana)	1977	Israel	CLSU
O. niloticus (Ghana)	1977	Singapore	BFAR
O. aureus (Israel)	1977	Singapore	BFAR
O. aureus (Israel)	1978	Singapore	SEAFDEC[d]
O. niloticus (Ghana)	1979	Taiwan	SEAFDEC
*O. aureus**	1979	Lake Hule, Israel 1958	CLSU/ICLARM
*O. niloticus***	1979	Israel, origin Ghana	CLSU/ICLARM
Red tilapia (hybrid)	1979	Taiwan	SEAFDEC
Red tilapia	1981	Taiwan	Private sector
O. aureus (Israel)	1982	Israel	Private sector
O. niloticus (Ghana)	1982	Israel	Private sector
Red tilapia	1982	Taiwan	Private sector

[a]Bureau of Fisheries and Aquatic Resources.
[b]Laguna Lake Development Authority.
[c]Central Luzon State University.
[d]Southeast Asian Fisheries Development Center.
*100-200 fry from a single pair spawn; no longer available.
**100-200 fry from a single pair spawn from the Gan Shmuel hatchery imported to CLSU (BFAR took a founder population 30 ♀♀, 10 ♂♂ from descendants in 1983); now widely used in aquaculture.

There used to be a lot of production of *O. mossambicus* from brackishwater milkfish ponds (of which there are about 200,000 ha) but this species came to be regarded as a pest.

Current tilapia production in the Philippine exceeds 50,000 t/year. Most comes from freshwater cage and pen culture (about 1,000 ha) and freshwater pond culture (about 20,000 ha). The current status of the Philippine tilapia culture industry is described by Guerrero (1987).

Almost all freshwater reservoirs have been stocked with *O. niloticus*. This has increased production tremendously, because the native fish fauna is rather impoverished.

The Philippine Bureau of Fisheries and Aquatic Resources' National Freshwater Fisheries Technology Research Center (NFFTRC) in Muñoz, Nueva Ecija has been identified as the National Tilapia Broodstock Center. It was constructed in 1979 with assistance from the United States Agency for International Development (USAID). The NFFTRC is evaluating different strains of *O. niloticus* for pond and cage culture systems and is propagating the same for dispersal to fish farmers and commercial hatcheries. Its roles are to maintain the quality of tilapia cultured in the Philippines and to supply fry and fingerlings and extension services.

The NFFTRC has obtained three different strains of *O. niloticus*: called 'Israel', 'Singapore' and 'Taiwan'. The 'Singapore strain' came from the Freshwater Fisheries Station (Binangonan) of the Southeast Asian Fisheries Development Center in August 1981: a total of 95 females and 54 males. The Israel strain was obtained from a collaborative project between ICLARM and the Freshwater Aquaculture Center (FAC) of Central Luzon State University (CLSU) in March 1982: founder stock 30 females and 10 males. This came from the original 1979 introduction of 100-200 fry from a single pair spawn (Table 5). The 'Taiwan strain' was introduced from Taiwan in May 1983 and May 1984 with assistance from USAID and ICLARM: the totals were 1983, 150 females plus 50 males; 1984, 16 females, 24 males.

O. aureus was introduced to the NFFTRC from Taiwan, again with USAID/ICLARM assistance in February 1984: 185 females and 60 males. The NFFTRC also has a stock of red tilapia obtained from FAC/CLSU in August 1983: 100 females and 50 males. All the above figures refer to survival of founder stocks.

These species and strains are maintained in separate breeding ponds, with close monitoring of their growth. The *O. niloticus* strains have been ranked for growth performance as follows: Israel > Singapore > Taiwan. *O. aureus* and red tilapia are not mass-produced for distribution to farmers as these might interbreed with the farmer strains of *O. niloticus*.

The NFFTRC therefore concentrates on distributing *O. niloticus*, 'Israel' and 'Singapore strains'. About 16 million fry and fingerlings have been distributed so far: 50% Israel and 50% Singapore. The recipients range from small backyard operators to large commercial operators. In trials with farmer cooperators, the 'Israel strain' has shown growth rates ranging from 1.8 to 4.0 g/day. The results for 'Singapore strain ranged' from 1.5 to 2.5 g/day. Therefore, the 'Israel strain' is preferred. The 'Taiwan strain' gives inferior growth rates. It is maintained for future genetic research but not mass-produced or distributed.

The NFFTRC is planning future work to improve tilapia broodstock in collaboration with FAC/CLSU and ICLARM. This will involve acquisition of new genetic material, hybridization and selective breeding programs. A Tilapia Industry Development Program has been proposed, comprising genetic improvement, hatchery technology development (including mass-production of monosex fry), technology verification and extension components.

Aside from government facilities there are a few private hatcheries conducting their own tilapia broodstock development programs. These companies are the Hantex Aquaculture Corporation, Crust-Asian Resources, Inc., the Meralco Foundation Agro-Aquatic Development Corp. and Aquatic Biosystems. Some private facilities maintain at least two strains/species of tilapia, inbreeding each and crossbreeding the two for production of good quality fingerlings. Mass selection is also applied. Farmers strive to avoid contamination of *O. niloticus* by *O. mossambicus*. They can easily differentiate between the species. Introgressive hybridization has been studied by the University of the Philippines and ICLARM (Taniguchi et al. 1985; Macaranas et al. 1986).

Research projects on genetic improvement of tilapia supported by the International Development Research Centre (IDRC) of Canada are being implemented by the FAC/CLSU (Abella et al. 1986) and the Southeast Asian Fisheries Development Center (SEAFDEC) Aquaculture Department. The objectives of these projects are to evaluate the available tilapia

stocks used for pond/cage culture, and to develop improved strains and/or hybrids for commercial hatcheries

Discussion

Dr. Pullin commented that there are still some information gaps concerning the origin of some introductions of tilapias to the Philippines. For example, what were the origins of the introductions from Singapore and Taiwan? He suggested that these probably came via Israel.

Dr. Lester praised Mr. Tayamen and the NFFTRC staff's approach of testing the different strains in various environments. He added that whereas the status of cultured tilapia populations in the Philippines is in many cases rather mixed-up, the NFFTRC stocks are well-maintained and monitored. Dr. Lester reported that SEAFDEC had told him that the original introduction of 'Singapore strain' to the Philippines consisted of less than 20 fish. The original Israeli broodstock held at NFFTRC are now beginning to die off, therefore a replacement strategy has to be followed. Dr. Lester recommended that a strong selection program be initiated in the Philippines, starting with the strains held at NFFTRC and CLSU/FAC, while trying to minimize interbreeding with feral *O. mossambicus*.

Dr. Hulata agreed with Dr. Pullin that the Singapore and Taiwan strains probably came from Israel and added that it is difficult to trace the exact records. The 1982 Israeli strain introduction to the Philippines was done directly from the Dor station and is therefore Ghana strain.

There was further discussion on introductions of tilapias to the Philippines, the main outcome of which was agreement that there was no clear access in the Philippines to *O. niloticus* from sources other than 'via-Israel'. The 1972 introduction of *O. niloticus* from Thailand (Chitralada strain) has not been maintained as a separate stock and there are plans for a reintroduction.

Mr. Balarin asked why *O. niloticus* is such a successful species for culture - in contrast to the *O. mossambicus* introduced previously? Is *O. niloticus* inherently a better species or have the farmers and culture technology just developed to a stage at which they have come to accept tilapia?

Dr. Guerrero commented that the introduction of *O. niloticus* changed the whole status of tilapia culture in the Philippines. This species is much more acceptable to consumers. Without the introduction of *O. niloticus* the Philippine tilapia culture industry would not have developed to its current status (over 50,000 t/year). *O. mossambicus* has several negative features, such as prolific breeding and dark coloration. The Philippine stocks of *O. mossambicus* are highly inbred. Of course, better farm management has played a part, but *O. niloticus* is clearly a superior species. The private sector has been very active in promoting *O. niloticus* culture.

Dr. Wohlfarth commented on the history of *O. mossambicus* in Asia. It was discovered 'accidentally' in 1938 in Java by an overseer (Schuster 1952). The population was two females and three males. After this, the picture is not clear because Dr. Schuster was interned as a prisoner of war by the Japanese. However, on his return to Indonesia, several years later, he found that *O. mossambicus* had spread throughout the country. It spread further - all over the Far East. The point is that apart from this first observation by Schuster in Java, we have no record of *O. mossambicus* being introduced to Asia from Africa. Therefore it could be that all the Asian populations derive from this extremely small number of fish. This could be one of the reasons why they perform so poorly. The African stocks may have very different characteristics.

Dr. Pullin added that this may also be a factor in the decline in *O. mossambicus* populations in some areas. For example, the Chitralada strain of *O. niloticus* appears to have avoided interbreeding with feral *O. mossambicus* in Thailand and *O. mossambicus* is now not as widespread as before in some areas of Thailand.

Dr. Guerrero reported that *O. mossambicus* is disappearing from some locations around Laguna de Bay, Philippines.

Mr. Manob Tangtrongpiros confirmed that *O. mossambicus* populations are declining in Thailand.

Dr. Moreau asked whether *O. mossambicus* and *O. niloticus* hybridize in man-made lakes in the Philippines.

Dr. Guerrero replied that there has been some hybridization. Moreover, the *O. mossambicus* present in irrigation systems and other watercourses interbreed with farm stocks of *O. niloticus*.

Dr. Pullin referred to the papers by Taniguchi et al. (1985) and Macaranas et al. (1986) which illustrate this problem. The tilapia farms in the Philippines that are the least advanced in broodstock management, for example some in Mindanao, have *O. niloticus* with the highest degree of introgression of *O. mossambicus* genes. There is a correlation between level of broodstock management and degree of introgressive hybridization.

Dr. Lester commented that some Philippine farmers may be actually selecting for an increase in *O. mossambicus* genes in their broodstock. They harvest the large fish and thereby select for small, fast-maturing, prolific fish (all traits of *O. mossambicus*).

Dr. Smitherman asked about the effects of pond depth on reproduction. Dr. Guerrero replied that reproductive output is highest in shallow waters, perhaps because of higher temperatures and oxygen availability causing stress.

Thailand

Mr. Manob Tangtrongpiros

Oreochromis niloticus was introduced to Thailand on 25 March 1965 by His Royal Highness Prince Akihito, the Crown Prince of Japan. Prince Akihito sent 50 fingerlings to His Majesty the King of Thailand. They were first kept in a 3-m^2 concrete pond before transfer on 7 May to a 10-m^2 earthen pond. At that time there were 19 males and 19 females surviving with average weights 16 g and 21 g, respectively (DOF 1966). [Those that bred successfully would probably have been larger and fewer in number - Editor].

The fish were called 'pla nil' (which means 'black fish' in the Thai language). In March 1966, the fish having bred successfully, His Majesty the King gave 10,000 fingerlings to the Thai Department of Fisheries and then the fish were distributed to 15 inland fisheries stations throughout the country for further propagation. The fish were first distributed to fish farmers in 1967. Tables 6 and 7 give the seed production by the Department of Fisheries and the annual production of *O. niloticus* in Thailand from 1972 to 1982. The production in 1985 was 75,254 t.

Table 6. Production of *Oreochromis niloticus* fry by the Thai Department of Fisheries (1972-82).

Year	Millions of fry	Year	Millions of fry
1972	8.2	1978	18.4
1973	9.2	1979	19.1
1974	9.1	1980	18.0
1975	11.6	1981	17.5
1976	11.1	1982	14.4
1977	11.8		

Table 7. Annual production (t) and value (million Baht)* of *Oreochromis niloticus* in Thailand (1975-1982): source - Thai Department of Fisheries.

Year	Production (t)	Value (million Baht)	Year	Production (t)	Value (million Baht)
1975	2,258	26.3	1979	3,248	50.6
1976	2,826	36.3	1980	5,115	74.1
1977	3,074	41.6	1981	5,455	81.6
1978	3,624	47.4	1982	7,104	112.0

*US$1.00 = 25 to 26 Baht.

Fish genetics research on tilapias, carps and catfish has increased in Thailand since 1982. Electrophoretic analyses have shown that the Chitralada strain of Nile tilapia has remained pure. The effects of various management techniques on the genetics of broodstock are now being studied on farms in northern Thailand. The early indications are that inbreeding is less of a cause of genetic deterioration than negative selection (choice of poor broodstock from production facilities). So far the study has involved four private farmers in Chiengmai and some fisnery station stocks. In investigation of 30 selection procedures, 19 were found to involve negative selection. The average selection intensity was 0.85.

In a further study on the realized heritability of growth rate improvement in Thai red tilapia (an *O. mossambicus/O. niloticus* hybrid), Jarimopas (1986) recorded realized heritability (h^2) values of 0.17 for length and 0.19 for weight. These are the first data to show that growth improvement in tilapia can be a moderate to highly heritable trait. [Previous work is reviewed by Pullin and Capili (in press), see Appendix I - Editor].

Discussion

Dr. Lester asked whether there had been any further introductions of *O. niloticus* to Thailand since the 1965 introduction of the strain via Japan.

Mr. Manob Tangtrongpiros replied that in 1983 a further introduction was made of about 1,000 fingerlings from Israel. In subsequent comparative trials of growth performance between the Chitralada strain and Chitralada strain-Israel strain hybrids, the Chitralada strain was found to be superior.

Dr. Pullin said that he had asked for clarification from Japan of the exact origin of the strain sent by the Crown Prince to Thailand. Enquiries made by Dr. Kenneth Ruddle, National Museum of Ethnology, Osaka, to a teacher of the Crown Prince had confirmed that the origin was Egypt. The details are given in Pullin and Capili (in press) (Appendix I). Dr. Pullin asked whether the Israeli strain of *O. niloticus*, imported to Thailand in 1983, was still being maintained.

Mr. Manob Tangtrongpiros replied that the Israeli strain had now been eliminated because its hybrids with the Chitralada strain gave poor performance.

Dr. Pullin remarked that the Chitralada strain performs very well in Thai aquaculture. Unlike many of the populations of so-called '*O. niloticus*' in the Philippines (which are in fact introgressed hybrids with *O. mossambicus*) the Chitralada strain appears to be relatively pure *O. niloticus*. Electrophoretic studies at 21 loci on a sample of 20 fish from the Asian Institute of Technology (AIT), done at the University of the Philippines, Marine Science Institute (UPMSI), have confirmed the purity of this strain. However, the observed heterozygosity of the sample was below that recorded from earlier studies in Japan (see discussion in Pullin and Capili (in press) - Appendix I).

Mr. Manob Tangtrongpiros added that *O. niloticus* stocked into open waters in Thailand usually failed to establish large populations and asked for comments as to why this might be so. He thought that the main reason might be predation by fish like *Channa* spp. There was general agreement on this.

Mr. Chen Foo Yan confirmed the tremendous abundance of the predator *Channa striata* in Thailand but added that young *Channa striata* shoals were sometimes attacked by *T. zillii*.

Dr. Pullin referred to records of an introduction of *T. rendalli* to Thailand in 1955. According to Welcomme (1981) this probably came from Zaïre, perhaps via Belgium, but was "not popular and (was) disappearing throughout the country as (it) cannot compete with local species". Dr. Pullin added that no one to whom he had spoken in Thailand knew where to find *T. rendalli* now.

Regarding the origin of red tilapia in Thailand, Dr. Lowe-McConnell reported that in May 1969 she collected one specimen from a population in a pond at Kasetsart University. The population had only a few red-colored individuals. The specimen was examined by Dr. Trewavas and is deposited in the British Museum (Natural History; registration number

1970.3.2.1). As it is of small size (47 mm SL; 62 mm TL) only meristic characters were thought useful for determining its affinities. The characters recorded were as follows:

Characters	Range of values for *Oreochromis niloticus*	Range of values for *Oreochromis mossambicus*	Thai specimen
No. of scales (lateral line series)	(30) 31-34	30-32	31
No. of scale rows on cheek	2 (or 3)	3 (or 2)	3
Gill raker count (lower)	18-26	14-20	19
[Modes]	20-22 in different populations	17-18	
Dorsal fin - mode	XVII		

Mr. Manob Tangtrongpiros said that this fish might be a hybrid between *O. mossambicus* and *O. niloticus*. *O. mossambicus* was introduced to Thailand from Malaysia [in 1949 according to Welcomme (1981) - Editor] and was spread to northeastern Thailand. In 1974, some red tilapia were found in a pond in northeast Thailand. They were assumed to be hybrids.

Dr. Pullin remarked that some Thai 'red tilapia' were examined by UPMSI/ICLARM at the same time as the Chitralada sample referred to previously. These fish also came from AIT. The results were as follows:

Samples (n = 13) were analyzed at the UPMSI laboratory. Results of the analysis using diagnostic loci (isozymes which are divergent between *O. niloticus* and *O. mossambicus*) showed that *O. mossambicus* and *O. niloticus* genes are present as follows:

Locus	Frequency of *O. mossambicus* allele	*O. niloticus* allele
Gpi - 1	0.385	0.615
Mdh - 1	0.423	0.577
Sod	0.154	0.846
Mp - 2	0.038	0.962
Mp - 3	0.125	0.875
Sdh	--	--
Mean Frequency*	0.225	0.775

*Computed using 5 loci only, excluding the Sdh locus.

At the Sdh locus, the scores were incomplete because of poor resolution but there was a predominance of the *O. mossambicus* allele.

Polymorphism was also observed at the Idh-1 and Adh loci. At the Adh locus, *O. mossambicus* and *O. niloticus* are not totally divergent. Thus, what caused this unusual Adh polymorphism cannot be ascertained for now due to lack of data from more tilapia species (reference markers).

MacAndrew and Majumdar (1983) consider Idh-1 as a discriminatory locus for *O. aureus*. Their *O. aureus* displayed a higher allele than *O. niloticus* and *O. mossambicus* (both possessed

Idh-1^{100} allele) which is similar to the Taiwan *O. aureus* analyzed in the UPMSI laboratory. Three-banded heterozygotes were observed at the Idh-1 locus of the Thai red tilapia which is strong evidence for the presence of *O. aureus* genes.

Regional aspects: Singapore and Malaysia
Mr. Chen Foo Yan

Tilapia culture is increasing in Asia, particularly in China (for integrated crop-livestock-fish farming), the Philippines, Taiwan and Thailand. There is less interest in tilapia in the Indian subcontinent, where carps are preferred. There is some tilapia culture in Indonesia and Malaysia, which may develop further, and red tilapias are being cultured in seawater (30 ppt) tanks and net cages in Singapore.

There is an interesting strain of *O. mossambicus* in a reservoir in Singapore. It is a short, deep-bodied fish; rather disc-like in appearance like a pompano. It can be easily recognized from other populations of *O. mossambicus*. Morphometric characters probably therefore will not be very useful in distinguishing different tilapia populations under certain "environmental" conditions. This is a good example of the plasticity of tilapias in different environments and fish communities - in this case, heavy predation by *Channa micropeltes*.

'Asian strains' may be of doubtful purity. It is a difficult and expensive task to keep strains and species separate. In the research studies on hybridization at Batu Berendam, Malacca, Malaysia, some 15-17 years ago, nine 400-m^2 ponds were used to maintain pure species (*O. mossambicus* and *O. urolepis hornorum*): three ponds for males; three ponds for females and three ponds for breeding. The *O. mossambicus* used here came from Pietermaritzburg, South Africa. The first introduction of *O. mossambicus* to Singapore was during the Japanese occupation. This strain still survives in the Botanical Garden and in the lake of the Seramban Sports Club.

Other Countries

Israel
Dr. G. Hulata

There are records of four species of tilapia occurring naturally in Israeli waters: *Oreochromis aureus*, *Sarotherodon galilaeus* and *Tilapia zillii* in the Jordan river system and *O. niloticus* in one stream close to Tel Aviv, completely separated from the Jordan system (Goren 1974). Fig. 22 gives the natural distributions of *O. aureus*, *O. niloticus* and *T. zillii*. The *O. niloticus* stock was probably introduced from Egypt during the Turkish or British occupation periods. [Dr. E. Trewavas thinks rather that it might have reached the River Yarkon during past Nile floods. Specimens from the Yarkon are in the British Museum - Reg. No. 1927 - Editor]. *T. zillii* is found all over the country.

Up to 1963, most of the mouth brooding tilapias in Israel were erroneously called '*Tilapia nilotica*'. Thereafter the situation was clarified by Dr. Trewavas following the hybridization experiments by Prof. L. Fishelson. Fishelson (1962) obtained all-male progeny from hybrid crosses between so-called '*T. nilotica*' from the stream near Tel Aviv and the so-called 'blue tilapia ' from the Jordan system (actually *O. aureus*).

There are now no more undisturbed native *O. aureus* or *O. niloticus* in Israel. The *O. aureus* stocks used by tilapia culturists were derived from the Jordan system stocks. These have been maintained by a number of different farmers and the Dor station since the 1950s. The native *O. niloticus* was never used for culture.

The *O. niloticus* used for culture in Israel derived from several introductions from Africa during the 1960s and 1970s:

a. 1969-1970; two introductions (177 and 184 fish), *O.n. eduardianus* from Kajansi Fish Culture Station, Uganda to the Gan Shmuel and Ein Hamifratz hatcheries - called 'Uganda' strain,

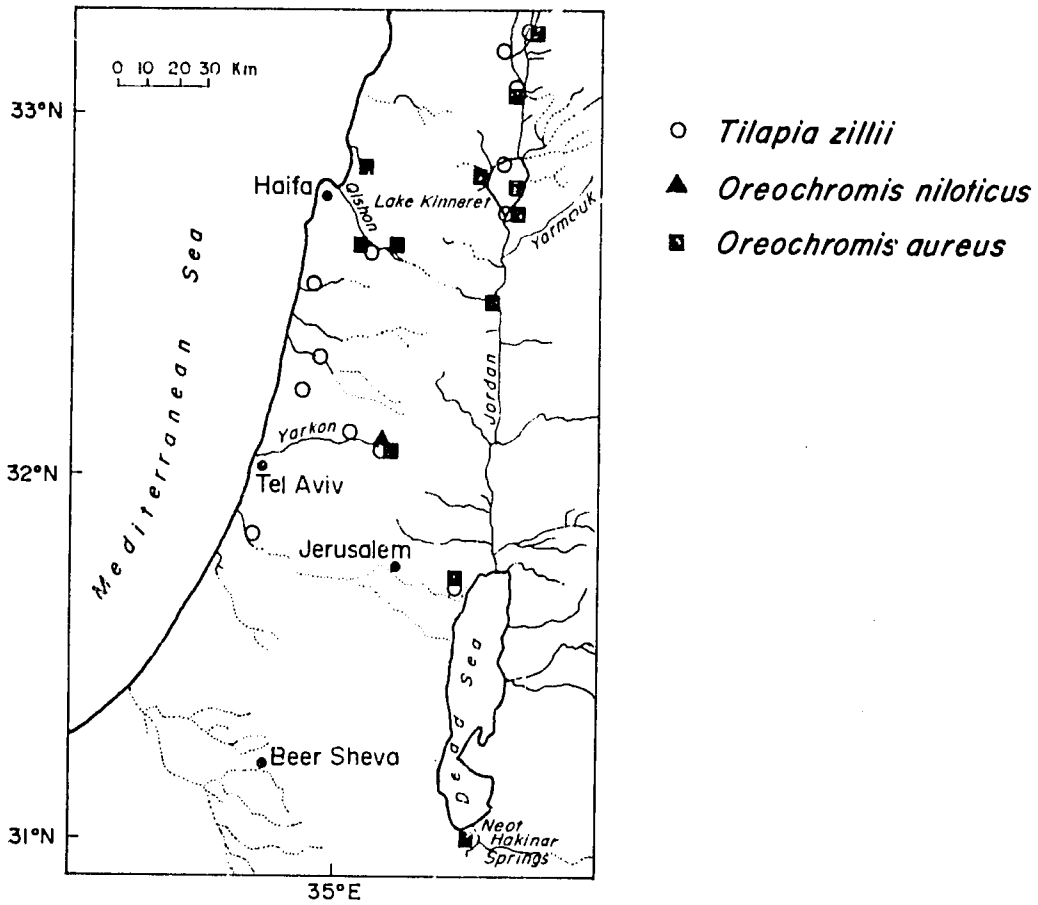

Fig. 22. Distribution of *Tilapia zillii*, *Oreochromis niloticus* and *O. aureus* in Israel: compiled from Goren (1974).

b. 1966; *O.n. vulcani* from Lake Rudolf (Kenya). Fry collected by Y. Pruginin from the mouth of a single female, sent to the Dor Station (Pruginin et al. 1975); and

c. 1974; *O.n. niloticus* from Lake Volta, Ghana; 50 fish were shipped, 9 females and 2 males survived - called 'Ghana strain'.

The Ghana strain is the most widely used in Israel. It is kept by most farmers for hybridization with *O. aureus*. *O.n. vulcani* has been used by at least one commercial farm. However, this subspecies is dark in color and is not used much. In the last 10 years, nearly all farmers have used *O.n. niloticus* Ghana strain or *O.n. eduardianus* Uganda strain. The source for the latter is the Ein Hamifratz hatchery, which has used both these strains.

A number of other introductions have been made for experimental purposes: for example, *O.n. niloticus* (300 fingerlings) and *O. aureus* (240 fingerlings) from Lake Manzallah, Egypt (supplied in 1984 by the University of Stirling) and *O.n. niloticus* from Ismailia Canal, one of the distributaries of the Nile River (collected in 1982 by Dr. A. Khater and distributed to Israel and Auburn (ca. 20 males and 60 females). These populations are kept at the Dor station and other experimental facilities and have not yet been spread to any farms. Escapees from the Dor station can go to only one stream, which drains directly to the sea.

Other introductions made for experimental purposes are kept in isolation, mainly at Dor or various universities.

These include: *O. mossambicus*, introduced from Natal, Republic of South Africa, in 1975; *O. urolepis hornorum*, one introduction from Pentecoste, northeast Brazil (ex-Bouaké, Côte d'Ivoire; previous origin not known) in 1977 (145 fingerlings) and another introduction from Jamaica by a commercial farmer (details and previous history unknown); red tilapias, one a Taiwanese strain obtained through Panama, another from the Philippines (both introductions by commercial farms) and a more or less continuous flow of what are probably red *O. mossambicus* coming in with the aquarium trade from the Far East.

In 1987, a further stock of red *O. niloticus* was obtained from Stirling University (80 fingerlings, offspring of 6 pairs). Finally *O.n. niloticus* 'Ivory Coast strain' (125 fingerlings) was introduced in 1977 along with *O. urolepis hornorum* from Pentecoste, Brazil. This stock was destroyed in 1984 because it gave poor fry production in hybrid crosses with *O. aureus*).

The lack of control over introductions by the private sector and through the aquarium trade gives cause for concern. Thankfully, there is no record yet of *O. mossambicus* or closely related species having escaped and become established in the Jordan system.

Discussion

Dr. Villwock asked when the native *O. aureus* stocks disappeared from the Jordan valley. He added that he had found a well-isolated population of this species in 1964 in the Ain Fashkha springs on the northwest shore of the Dead Sea.

Dr. Hulata replied that *O. aureus* has not disappeared from the Jordan system but the populations have become mixed up with *O. niloticus* since the mid-1970s because of escapees from fish farms in Upper Galilee. Here there are three main streams on the catchment of the Jordan River. The escapees would be *O. niloticus* and *O. niloticus* x *O. aureus* hybrids. Moreover, Lake Kinneret is stocked with fingerlings every year to enhance the commercial fishery. For several years the material stocked was *O. niloticus* x *O. aureus* hybrids. There is probably no surviving isolated population of pure native Israeli *O. aureus*.

Dr. Hulata added that the Ain Fashkha population has been described by Chervinski (1968) as '*Tilapia aurea exul*.' It differs from other *O. aureus* in Israel. However, it is probably no longer isolated because about 10 years ago a fish farm was established in the Kibbutz called Kalia, close to this spring (less than 2 km) and it is probable that farmed fish have escaped and interbred with those in the spring.

Dr. Lowe-McConnell asked for further clarification on the introductions of *O.n. vulcani* from Lake Rudolf (Lake Turkana). Dr. Hulata replied that the full details are not available but that there were definitely two introductions, one from the main lake and one from a crater lake. The latter was originally called 'vulcani' and the former 'Lake Rudolf introduction.' They were kept separated at first but are now mixed.

Mr. Balarin asked whether any comparative performance trials had been made between the various strains. Dr. Hulata responded that the strains introduced in the 1970s (Ghana, Uganda and Lake Turkana) have not been compared for their growth performance because the main commercial interest has been production of all-male *O. niloticus* x *O. aureus* hybrids (Mires 1977; Wohlfarth and Hulata 1983). Therefore comparisons have been limited to all-male hybridization success, backed up by electrophoretic studies. The 'Ghana strain' was found to be the most homogeneous and was recommended for commercial hatchery use in the belief that this would give higher percentages of all-male hybrid progeny. This worked well sometimes; others not so well. However, comparative growth performance tests have now been started for the more recently introduced material (Wohlfarth et al., in press).

Dr. Pullin asked about future directions in tilapia genetics research in Israel. Where would Israeli scientists seek new genetic material and would a switch from all-male fry production by hybridization to sex reversal by hormone treatment affect future research planning?

Dr. Hulata replied that the Israeli private sector would continue to pursue its own improvement work. The governmental program, for example at the Dor station, may or may not proceed in the same direction as the private sector. All-male fry production by both methods (hybridization and sex reversal) is continuing at present. Some farms still maintain separate 'good' stocks of *O. niloticus* and *O. aureus* that will give 95 or higher percentage of all-male

hybrid progeny. Examples are the Nir David and Ein Hamifratz hatcheries. They sell mainly all-male hybrid fry. Other farms prefer sex reversal and they are less critical about the broodstock they use - the main criterion being high fecundity. They sell hormone-treated all-male fry (actually about 99% male). This can cause a lack of broodstock management which is potentially dangerous. The good pure farmed stocks of the two species may be lost - as were the native stocks.

Thus, the future direction is not clear. The use of *O. niloticus* x *O. aureus* hybrids from good parental stocks for production purposes has clear merits. It avoids inbreeding problems. The current research thrust at Dor is to compare the strains which can contribute the best production traits (for example, growth rate, cold resistance, body shape, etc.) to this system - not just high percentages of males. This has been neglected until very recently.

USA
Dr. R.O. Smitherman

Tilapias have been introduced to a number of States, including Hawaii. Hawaii has *O. mossambicus* and red tilapias, among other species (though not *O. niloticus*) and the details of their origins are not all known. [*Oreochromis mossambicus* and *Tilapia zillii* are established in California (Knaggs 1977) - Editor]. Further introductions of tilapias are banned. This contribution is focused on the stocks available at Auburn University, Alabama. These are used mainly for research and teaching.

O. mossambicus was the first species introduced in 1955. A group of about 20 fry were obtained from the Steinhart Aquarium, San Francisco (previous origin unknown), and this line has been maintained at Auburn ever since.

In 1957, ten *O. aureus* were introduced to Auburn from Israel. Six died and the remaining founder population consisted of one female and three males. From these have been derived all the widespread *O. aureus* populations in the USA, including a feral population in the Florida lakes which supports a fishery of several million pounds/year. There are some isolated phosphate pit lakes in Florida with populations of this strain that have not had contact with any other tilapias. Several research stations, including government stations, also maintain populations of this strain.

In 1974, *O. niloticus* (origin Bouaké, Côte d'Ivoire) was introduced from Pentecoste, northeast Brazil: about 100 fry. The possibilities of bottlenecks from the origin(s) of this strain (pre-Bouaké, to Bouaké, to Brazil and from there to Auburn) are apparent. [See Discussion p. 40-41 - Editor]. Also in 1974, about 100 fry of *O. urolepis hornorum* were introduced to Auburn from Pentecoste.

In 1982, about 200 fry of *O. niloticus*, 'Ghana strain' were introduced to Auburn from Israel. This was part of a collaborative Egypt-Israel-USA program of strain testing. The same year, about 66 subadult females and 20 males of Egypt strain *O. niloticus* were introduced. Comparisons between 'Ivory Coast', 'Ghana' and 'Egypt strains' revealed that 'Egypt strain' fish were the most heterozygous. The 'Egypt strain' also tested the best in several commercially important traits.

Also in 1982, a stock of red tilapia was obtained from Florida ('Sipe' strain). This appears to have been developed as a mutant colored *O. mossambicus* crossed with *O. urolepis hornorum*. The *O. mossambicus* used by Mr. Mike Sipe in making this cross was probably acquired through the aquarium trade, perhaps from Singapore. The *O. urolepis hornorum* was from the Bouaké-Brazil-USA stock. Efforts followed to develop a cold-tolerant red tilapia hybrid by further crossing with Egyptian strains of *O. aureus* and *O. niloticus*.

Further Discussion

Mr. Chen Foo Yan reported that in the early 1960s he sent *O. urolepis hornorum* from Singapore to Dr. William McConnel of the Fishery Cooperative Unit, Tucson, Arizona

(McConnel 1965). By 1969, these fish had hybridized with other tilapias. This was shown by electrophoresis.

Dr. Payne asked about the culture performance of the Florida red tilapias.

Dr. Smitherman reported that opinions differed on this.

Dr. Moreau reported that the *O. urolepis hornorum* kept at Bouaké and sent to Brazil were obtained from Malaysia. A shipment of fish was sent as a gift from Dr. G. Prowse to the Centre Technique Forestier Tropical (CTFT).

Mr. Chen Foo Yan reported that *O. urolepis hornorum* was introduced to Malaysia from Zanzibar in 1958.

Regarding the growth performance of red tilapias, using the index ϕ' devised by Moreau et al. (1986), Taiwanese and Philippine red tilapias have a growth performance as good as *O. niloticus* (Galman 1987; Galman et al., in press b). The ϕ' values given by Galman (1987) are as follows: Philippine red tilapia, 2.17-2.30; Taiwanese red tilapia, 2.11-2.27; cf. *O. niloticus*, 2.28 ± 0.48 (Pauly et al., in press).

Dr. Pullin invited comments on the implications of small founder stocks and low effective breeding numbers of broodstock for culturists and their selective breeding attempts.

Dr. Lester commented that theoretically even a small bottlenecked population can show a response to selection. However, a plateau will probably be reached very quickly because genetic variation has been lost. It is the accepted view in evolutionary theory that genetic variation buffers a population against catastrophic losses from environmental changes. In a managed environment, like a farm, such catastrophes are less likely than in the natural environment (where the more specialized an organism and the less genetic variation it has, the more likely it may become extinct). For domestication purposes therefore, inbreeding may be good or bad. The bad effects of inbreeding depression can be 'passed through' in some breeding programs - as has been done in plant breeding. However, inbreeding is not recommended for fish culture.

Dr. Villwock agreed that a population crash through loss of genetic variation in a farm environment is unlikely. However, he added that the loss of such variation in natural genetic resources is a very serious matter. For example, hatchery-reared fish stocked into natural waters may not be able to adapt and survive environmental changes.

Dr. Smitherman commented that tilapia culture in the USA is likely to gain popularity. However, it is hindered by restrictions; for example the only species available in California are *O. mossambicus* and *T. zillii* and introductions of other more useful species are banned. *T. zillii* is used to clear vegetation from drainage ditches. *O. mossambicus* is not well liked, but the Californian authorities assume that all other tilapias must be as 'bad' as *O. mossambicus*. There are some commercial operations starting in the States which are too cold for tilapia to survive other than in geothermal facilities. Auburn University would like to improve its stocks of *O. aureus* and *O. niloticus*, particularly the former, by further introductions. The need for monosex male production by hybridization and research to improve this technology has virtually gone. Hormonal sex reversal is the preferred method.

Dr. Pullin asked how the *O. aureus* from the very small Auburn founder stock (one female) had performed in culture in other countries in the Americas.

Dr. Smitherman replied that it has not really been evaluated as a single species in culture. It is normally used in hybridization work or polyculture. The indications are that by itself it grows almost as well as *O. niloticus*.

Dr. Pullin commented that so-called "Auburn" *O. aureus* kept at Central Luzon State University, Philippines, performs poorly and has a 'saddleback' deformity (Tave et al. 1983). Dr. Guerrero agreed but added that stocks are still maintained in the Philippines for future genetics research, even though its cold tolerance characteristics are not needed there.

There was a further discussion on the relative merits of *O. niloticus* and *O. aureus* with regard to growth performance. It was agreed that good comparative data are lacking but that *O. niloticus* seems at present to be a better species for tropical aquaculture.

Session III. Research Methods Used in Tilapia Identification and Genetic Research

Chairman: Prof. W. Villwock

Electrophoresis

Dr. R.S.V. Pullin

Electrophoresis encompasses a wide range of laboratory techniques. A recent overview is given by Jorgensen and Phillips (1985). Electrophoretic and isoelectric focusing techniques have been widely used by population geneticists and taxonomists to clarify the status of species and other taxa (Shaklee et al. 1982; Laird et al. 1982). Electrophoresis is a useful tool to document the status of wild and cultured stocks. It is not an end in itself. Important papers on electrophoresis of tilapia proteins have been published by Avtalion (1982), Cruz et al. (1982) and McAndrew and Majumdar (1983). Electrophoresis can provide a wide set of markers to delineate stocks and electrophoretic data can be used to indicate polymorphisms, estimate genetic distances, heterozygosity levels, etc. A good recent example of its usefulness is the study by Krieg and Guyomard (1985) comparing hatchery and wild stocks of brown trout.

The main disadvantages of electrophoresis are its cost and difficulty. It needs care and experience to produce good gels, especially for some loci. It is best done on a routine basis for good results and comparability of gels. The hardware and some of the biochemicals needed are expensive. Electrophoresis requires good laboratory facilities and a reliable, continuous power supply; not only for running the gels but also for cold storage of samples and biochemical reagents. It has not been developed to any significant extent as a field technique.

The work of Taniguchi et al. (1985), Macaranas et al. (1986) and Galman et al. (in press a) shows the utility of electrophoresis and isoelectric focusing in studies of tilapias cultured in Southeast Asia and Israel. Plate 1 illustrates some of the work done on Philippine stocks.

In summary, electrophoresis is a very useful technique. It can provide more reliable genetic markers than, say, body coloration (which can be very variable in different environments and also changes rapidly in anesthetized or dead fish). Electrophoresis is therefore useful for studying tilapia population genetics. It remains to be seen how much it can be used for the study of natural populations (given the difficult logistics of bringing together good sample material and the required laboratory facilities) and whether it can be developed to delineate intraspecific strains, rather than just species and hybrids.

Discussion

Dr. Harvey asked for further clarification on the possibilities of field application of electrophoretic techniques as this could assist in decisions over which material to collect.

Dr. Pullin replied that electrophoretic analysis of tissues from field samples would be highly desirable, but that the logistical difficulties are very great. Until these can be solved, collectors will have to make the best of alternative techniques such as accurate descriptions of morphology, color and meristic characters.

Dr. Lester replied that samples well-frozen and well-packed with dry-ice (solid CO_2) are usually good for most loci. He offered the assistance of his laboratory in making preliminary analyses of important material collected in the field after which the gels can be photographed for

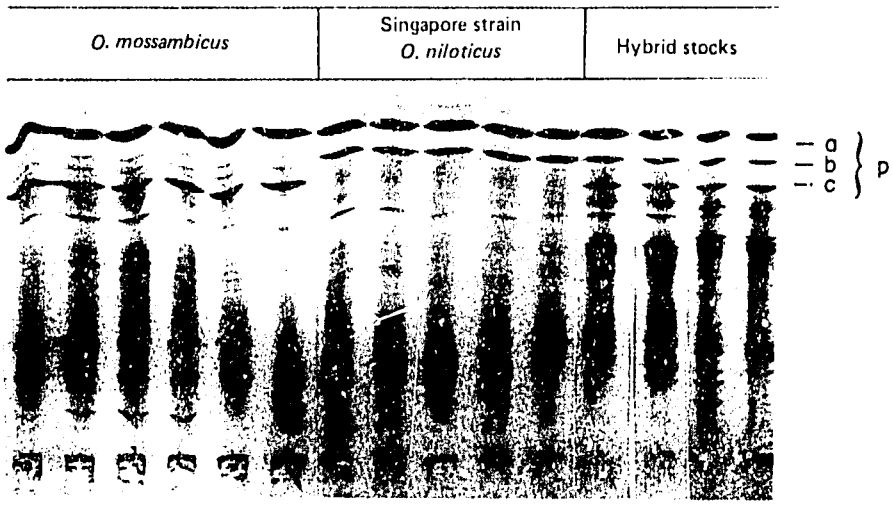

Plate 1. Typical skeletal muscle sarcoplasmic protein patterns of Philippine tilapias examined by isoelectric focusing on an Ampholine polyacrylamide gel plate at pH gradient 3 10. The parvalbumin region is designated P. Three banding positions are observed.

scoring (interpretation). Most enzymes remain unaffected when storage is below -20°C. However, dry ice storage and shipment is the surest method. Liquid nitrogen is also a good storage and shipment medium, but is more difficult to keep in contact with tissue samples.

Mr. Chen Foo Yan referred to his work (Chen and Tsuyuki 1970) on electrophoresis of tilapia hemoglobins, muscle myogen esterases and LDH. These can delineate different species and their F_1 hybrids very well. However, in studies on backcrosses of F_1 hybrids to parental stocks and on sibling crosses of F_2 hybrids it has been observed that there is segregation into the parental types. Therefore, in a situation of a mixed and freely interbreeding population of different species and hybrids, some markers may indicate that specimens are pure species, whereas they may in fact be hybrids. For example, *O. mossambicus* and *O. urolepis hornorum* have species-specific electrophoretic markers. An F_1 hybrid between these two species shows intermediate patterns. In backcrosses of the F_1 hybrids to either parent, there is segregation so that one of the parental patterns reappears. Also in F_2 hybrids, about 25% show the parental *O. mossambicus* pattern, 25% the *O. urolepis hornorum* pattern and the remaining 50% would be intermediate.

Dr. Pullin commented that in the studies on Southeast Asian cultured tilapias (Taniguchi et al. 1985; Macaranas et al. 1986), samples were taken from farms and research stations, but no experimental hybrids between *O. mossambicus* and *O. niloticus* were created. The results showed that there was a range of frequencies of *O. mossambicus* genes in the *O. niloticus* stocks, i.e., introgression. F_1 hybrids were exceptionally rare.

Dr. Wohlfarth added that electrophoresis is a very powerful tool for discriminating between species and for investigating the influence of one species on another when there is interbreeding. However, it seems to have very limited utility for investigations within a species. Moreover, the interpretation of and application of results from electrophoretic analyses need experience, a knowledge of genetics and great caution.

Dr. Pullin agreed but pointed again to studies such as that of Krieg and Guyomard (1985) on brown trout populations in France. This shows clearly a wide genetic variability in wild populations and a high degree of similarity between cultured stocks. Such investigations are very useful within a single species. They can estimate important genetic parameters. Similar studies should be made on wild and cultured tilapias, especially *O. niloticus* populations.

Dr. Hulata said that such studies are indeed very valuable for populations, but that the limitations of electrophoretic techniques are apparent when data are required for *individual*

broodstock. The problems mentioned by Mr. Chen Foo Yan then become critical. They can, however, be overcome by having enough discriminatory markers. With say five or six markers, the chances of making mistakes in assigning an individual fish to one group or another become so small as to be negligible. Therefore, provided that we have enough good markers, we can use electrophoresis to identify individuals as well as populations. However, there is a further difficulty here in that most of the good discriminating markers between tilapias are enzymes from internal organ tissues. There are not so many markers from tissues like blood, that can be sampled without killing the animals. Muscle biopsy is possible, but in general the need to keep fish alive for breeding purposes greatly reduces the availability of electrophoretic markers. The use of a limited range of markers from live broodstock has caused problems in interpretation of data in Israel.

Mr. Chen Foo Yan agreed with Dr. Hulata and said that his investigations had used markers from blood (hemoglobins), in which case the fish were kept alive, or enzymes from muscle, kidney, heart, liver and eyelens. If sufficient markers are used, the segregation problem could perhaps be overcome.

Dr. Moreau asked how many markers are 'sufficient'?

Dr. Pullin responded that the work referred to on Southeast Asian tilapias used five or six discriminatory markers between *O. niloticus*, *O. mossambicus* and their hybrids. This should be sufficient.

Dr. Lester asked why Israeli researchers found it necessary to mark individual fish; was it for the all-male *O. niloticus* x *O. aureus* hybridization research program?

Dr. Hulata affirmed this. In Israel, the first requirement for hybridization programs is to ensure that the parental fish do belong to the two species. *O. niloticus* and *O. aureus* are very similar in morphology and meristic characters; thus electrophoretic markers have been used as a check by hatchery managers on the identification and purity of their broodstock. However, the technique has not always been reliable.

Dr. Hulata added that even for checking populations there is a clear need to develop methods using markers that do not require the fish to be killed, otherwise the fish checked cannot be the same ones as those collected for breeding purposes. This is particularly true for collection of new genetic material for use outside its natural range. Shipments of tilapia are nearly always made at the fry or fingerling stage. At present it is almost impossible to test such individuals using electrophoretic markers and keep them alive.

Dr. Wohlfarth reported that on one occasion, unfortunately not documented, an Israeli tilapia breeder had retained both the broodstock which, on electrophoretic checking of species purity, he had been advised to keep and those that he had been advised to discard. The latter gave a higher percentage of male hybrid progeny! This information is anecdotal, but it is likely that broodstocks with 'poor' electrophoretic patterns with respect to species purity can give as good results in hybrid crosses to produce male progeny as those with 'good' patterns. This does not mean that electrophoresis does not 'work'. It does. However, when hatchery managers select their broodstock using advice based on electrophoretic data as the sole criterion, this can bring about reduced genetic variation. This has happened with Israeli *O. aureus* broodstock. There are many possible factors here, including inbreeding and genetic drift.

Dr. Wohlfarth summarized this as a hypothesis, as yet unsupported by quantitative evidence, that *O. aureus* broodstock in Israel has reduced genetic variation, possibly involving the loss of valuable genes, for which a root cause was the misuse of electrophoresis. The conclusions are: 1) to use electrophoresis to identify fish but to use performance testing when selecting for commercial traits and 2) to avoid misuse of electrophoresis.

Research on Tilapia Blood Groups

Dr. W. Villwock

A research group at the University of Hamburg has been working on fish blood groups, concentrating on cultured species, for four years. The work arose from basic studies on vertebrate evolution that posed the question, when did blood groups first evolve? For fish, the

potential value of blood groups as a tool to discriminate between closely related species or between domesticated/inbred and wild populations within a species was soon recognized.

The work commenced with common carp (*Cyprinus carpio*). Very recently, the group succeeded in isolating some erythrocyte membrane structures (Groth et al. 1984; Oberst et al., in press) and cloning specific antibodies to one of these. The group is sure that this will provide a useful technique for typing closely related populations by their blood groups. An immunological technique like this would be suitable for use in the field, unlike electrophoresis.

The group has now commenced work on *Oreochromis niloticus* using material from captive populations. Samples from wild populations are urgently needed. This is expected to become a very powerful technique for typing tilapias.

[Different tilapia species have been identified by an immunological method, presently under development (Timen and Avtalion, in press) and it is hoped that this may also be applicable to intraspecific variation - Editor].

Multivariate Analysis of Morphometric/Meristic Data

Ms. M.J.R. Pante

Despite the usefulness of electrophoresis to discriminate between tilapia populations and to determine their levels of genetic variation, this technique is rather expensive and laborious. Therefore culturists and researchers have begun to look for other traits to describe their populations. Some culturists in the Philippines regard the number of caudal fin bars in *Oreochromis niloticus* as an important character when selecting broodstock; i.e., a large number of well-defined bars is thought to be correlated with a high degree of 'species purity' and good performance. There is no hard evidence for this.

[Dr. E. Trewavas later contributed further information on this. The caudal bars increase in number as the fish grow. The subspecies *O.n. eduardianus* and *O.n. cancellatus* have less well-marked caudal bars than *O.n. niloticus* - Editor].

Under the research collaboration between the Marine Science Institute of the University of the Philippines (UPMSI) and ICLARM, morphometric and meristic data have been collected for multivariate statistical analysis from a number of tilapia populations cultured in the Philippines (Pante et al., in press). The aim of this is to find indexes that can be used by culturists and field biologists. The analyses described below were performed at the University of Houston, Clear Lake, in collaboration with Dr. L.J. Lester.

The technique used is called canonical discriminant analysis. Data were taken from two 'reference' populations: *O. niloticus* 'Ghana strain' from Israel cultured in the Philippines (I); *O. mossambicus* (M), a feral population from brackishwater; '*O. niloticus*-like' populations (introgressed hybrids) (P, S, T) (Fig. 23) and red tilapias (R, L) (Table 8).

In an analysis including caudal fin bars as a meristic character, red tilapias were easily separated out (having no caudal fin bars) but the *O. niloticus* and *O. niloticus*-like populations were closely grouped (Fig. 24).

In a further analysis, both morphometric and meristic characters were used (Fig. 24). The morphometric data, however, gave a separation between populations based mainly on size differences. The technique needs to be refined to analyze shape rather than size differences. This will be pursued using truss network techniques (Humphries et al. 1981; Brzeski and Doyle, in press).

So far these multivariate techniques can distinguish between species such as *O. niloticus* and *O. mossambicus* but they are not yet sufficiently developed for use in separating strains or closely related hybrids. It is the hope of the UPMSI/ICLARM/Houston group that further refinement of such techniques will lead to their becoming a useful tool, particularly for analysis of data collected in the field.

Table 8. Mean and standard deviation (in parenthesis below mean) of all characters (DSP, DR, AR, GRC, CFB, BD/SL, HL/SL, SL, IOW, OD) used in canonical discriminant analyses for *Oreochromis mossambicus* (M), *O. niloticus* (I), *O. niloticus*-like populations (P,S,T) and red tilapias (R, L) (after Pante et al., in press).

Character	*O. mossambicus*	*O. niloticus*				Red tilapia	
	M	S	P	T	I	R	L
Dorsal spine count (DSP)	15.92	16.42	16.75	16.68	16.90	17.00	16.80
	(0.474)	(0.642)	(0.669)	(0.572)	(0.632)	(0.707)	(0.405)
Dorsal ray count (DR)	11.92	12.55	12.90	12.85	12.76	12.15	12.88
	(0.526)	(0.828)	(0.709)	(0.662)	(0.479)	(0.899)	(0.563)
Anal fin ray count (AR)	11.30	10.42	10.55	10.00	10.48	9.31	10.25
	(0.608)	(0.642)	(0.504)	(0.599)	(0.506)	(0.855)	(0.494)
Gill raker count (GRC)	22.85	29.47	30.52	29.10	29.08	31.46	29.18
	(1.222)	(2.102)	(1.485)	(1.392)	(1.163)	(1.330)	(1.907)
Caudal fin bar (CFB)	0	8.12	7.75	5.13	7.40	0	0
	0	(1.343)	(1.171)	(1.239)	(1.236)	0	0
Body depth/Standard length (BD/SL)	56.04	63.68	63.67	51.45	51.62	64.09	58.09
	(3.765)	(2.120)	(2.170)	(2.129)	(1.879)	(2.460)	(3.109)
Head length/Standard length (HL/SL)	55.34	62.36	61.58	48.71	50.17	55.61	49.83
	(3.499)	(4.157)	(2.194)	(1.501)	(1.384)	(1.479)	(2.428)
Standard length (SL)	13.68	14.84	12.59	12.72	13.06	12.22	7.36
	(2.023)	(1.535)	(0.993)	(0.786)	(1.057)	(0.706)	(0.699)
Interorbital width (IOW)	1.54	2.11	1.76	1.29	1.30	1.56	1.04
	(0.155)	(0.223)	(0.192)	(0.102)	(0.156)	(0.100)	(0.096)
Orbit diameter (OD)	1.00	1.36	1.23	0.85	0.92	0.98	0.72
	(0.099)	(0.146)	(0.101)	(0.052)	(0.069)	(0.067)	(0.065)

Discussion

Dr. Lester confirmed that the technique can at present discriminate between species and some hybrids but that its application in studying intraspecific variation looks less promising.

Dr. Hulata asked whether these multivariate techniques are really suitable for field use as they require computing facilities, perhaps more powerful facilities than microcomputers? Moreover, there would be a long delay between the collection and interpretation of field data. Could a 'chart' be developed for field use so that specimens could be assigned to different categories, based on a number of measurements and characters, i.e., a more sophisticated kind of field key? If so, the technique would be very useful. Kuris et al. (1987) produced a chart for *Macrobrachium* correlating total length and carapace length. By simple measurements in the field and entering these on a chart, a male specimen can be assigned to a number of different groups: 'undifferentiated'; 'orange-claw'; 'blue claw', etc. Could something similar be done for tilapias?

Dr. Smitherman commented that it is the presence of different male morphotypes that makes this technique successful in the case of *Macrobrachium*. For the tilapias, schemes for identifying the different sexes and juvenile specimens would be necessary.

Ms. Pante replied that this would be an interesting option. However, the UPMSI/ICLARM/Houston group is planning to investigate the use of field photography of specimens and subsequent laboratory analysis of shape differences among strains by means of a digitizer and principal component analysis.

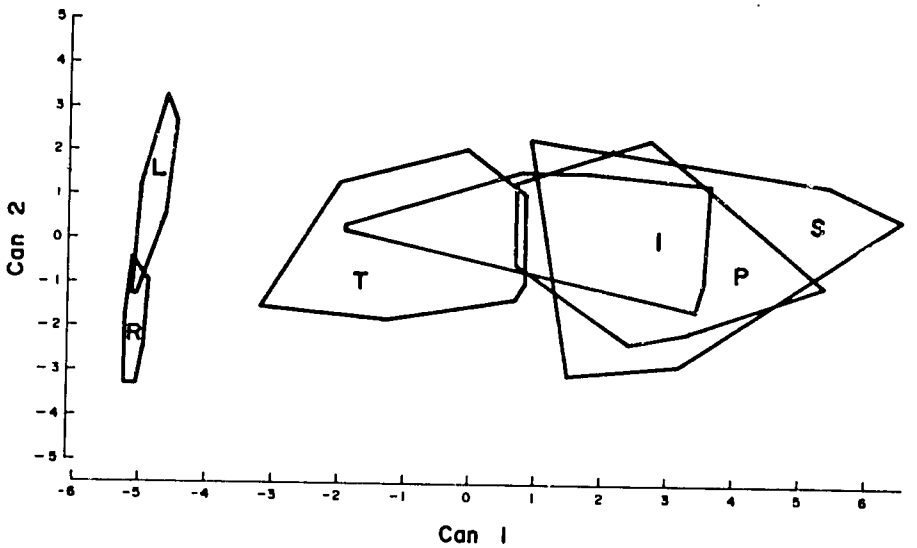

Fig. 23. Plot of first two canonical variates from analysis of meristic (DSP, DR, AR, GRC and CFB) characters of tilapias: *Oreochromis niloticus* (I); *O. niloticus*-like populations (P, S, T) and red tilapias (L, R). For an explanation of abbreviations used, see Table 8 (after Pante et al., in press).

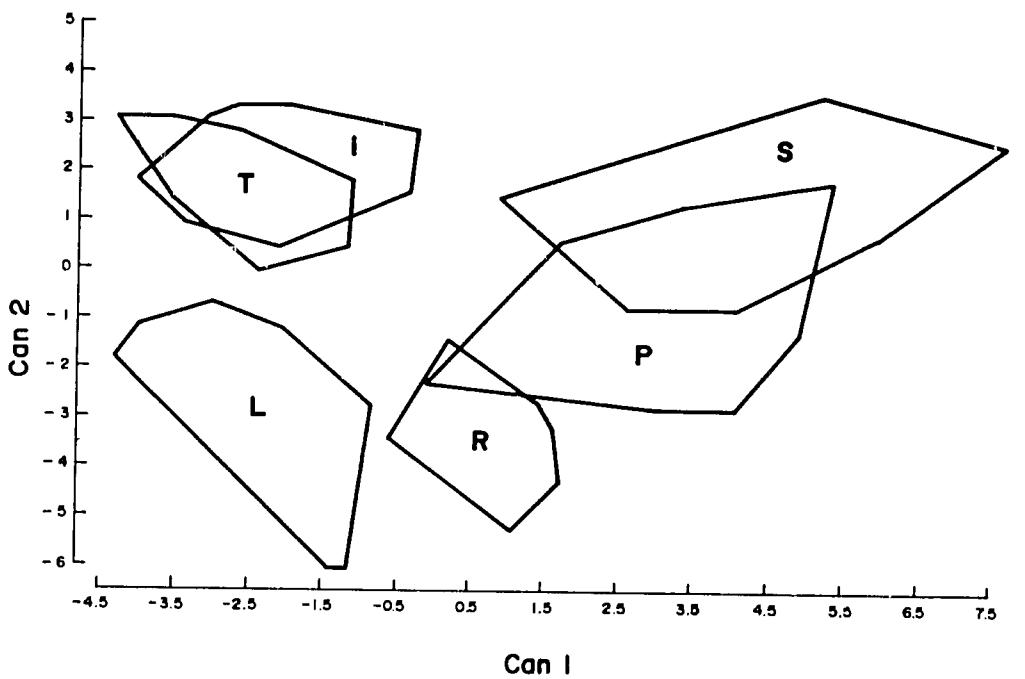

Fig. 24. Plot of the first two canonical variates from analysis of morphometric (BD/SL, HL/SL, IOW and OD) and meristic (DSP, DR, AR and GRC) characters of tilapias: *Oreochromis niloticus* (I); *O. niloticus*-like populations (P, S, T) and red tilapias (L, R). For an explanation of abbreviations used, see Table 8 (after Pante et al., in press).

Dr. Lester added that the objective remains to develop an index for use in investigations of intraspecific variation: for example, detecting population differentiation within the wide natural range of *O. niloticus*.

Dr. Pullin emphasized that the results obtained so far were quite encouraging. For example, these analyses placed so called Taiwan and Israel *O. niloticus* together; they may have been derived from the same source - Israel - although Taiwan has also imported this species from Egypt. They also have done at least as well as electrophoretic methods in discriminating between *O. niloticus* and *O. niloticus*-like (introgressed hybrid) populations and red tilapias. This is an impressive result. The refinement of such techniques to permit shape analysis in the field would be extremely valuable.

Dr. Thys van den Audenaerde reported that multivariate analytical techniques are being used more and more for population studies in many groups of animals. For the tilapias, there is the question of how to compare wild and cultured populations and strains. We can measure genetic distance, but what is really needed is a full picture of genetic variation in nature as well as in the very few strains at present in captivity. The very wide geographical range of *O. niloticus* presents a huge task in this respect.

Taxonomy and Identification Keys

Dr. R.H. Lowe-McConnell

Trewavas (1983) provides keys for identification of the mouth-brooding genera *Sarotherodon* and *Oreochromis* but her monograph is too expensive and large for field use. A field key, particularly for identification of tilapias of interest to culturists, is therefore required. Such a key has been prepared as a result of this workshop (Appendix III).

Some of the characters used in field keys, like male breeding colors and nest form, cannot always be observed. Another difficulty is that small/juvenile specimens can be very difficult to identify. For example, the juvenile stages of the four *Oreochromis Nyasalapia* species in Lake Malawi live in mixed shoals and are very difficult to assign to the separate species. They are best distinguished when in breeding coloration. Moreover, in situations in which species have become mixed through introductions and transfers, field keys can prove very difficult to use. However, field workers should be encouraged to use field keys and not to take the rather lazy attitude that there is now a hopeless situation because of hybridization. In many areas, a field key is still very useful, particularly when collecting from natural waters.

Dr. D.F.E. Thys van den Audenaerde

Field keys are certainly needed. One problem, however, is that field workers will encounter a lot of species and the confused state of tilapia taxonomy makes the situation rather complicated. Breeding males are always easy to identify; females and juveniles much less so.

All tilapia workers must be encouraged to take more trouble to check the identification of their fish by the characters that have been in use by taxonomists for many years. It is surprising that many tilapia researchers do not know how to do the simple things that are needed to identify tilapias, like making a gill raker count, scale count or dissecting out a pharyngeal bone. Such techniques should be described in a simple field handbook and training in such techniques should be widespread. For example the Leiden group working on haplochromine stocks had similar difficulties and so produced a handbook defining, for example, tooth morphology ('bicuspid', 'curved', 'strongly curved', etc.) by means of standard illustrations. A similar work would be very valuable for tilapias. The information can be gleaned from Trewavas (1983) by cross-referencing different pages and illustrations, but this is a work for specialists, not field scientists. Field scientists need basic training in tilapia morphology.

Finally, making a key valid for *all* tilapia species is extremely difficult. It is better to start with a description of general morphology from which fish can be assigned to the major groups and then to concentrate on those species of interest or potential interest for aquaculture. One idea

that may be of value is to produce identification sheets for a limited number of species. This is already done in the aquarium trade, using color prints. When new strains of tilapia are available, these can be entered on to an additional identification sheet which can then be added to the key. This would be very useful for aquaculturists

Discussion

Dr. Villwock commented that FAO has produced identification sheets for species from a number of different families. These could be used as a pattern.

Dr. Wohlfarth commented that a tilapia identification key is indeed needed and that he hoped those present would collaborate to produce one.

Dr. Fullin agreed but said that the problem is really twofold: 1) how to identify specimens in the field and 2) how to describe and record (keep a register) farmed stocks. These are rather different problems. For example, to establish and update an 'International Strain Register' for cultured tilapias, standard descriptive formats are needed. This has already been done for trout (Kincaid 1981) and catfish (Dunham and Smitherman 1984). For the wild populations, better field guides written by experienced taxonomists are needed.

Dr. Lester asked how a strain registry - for example the catfish registry - is run.

Dr. Smitherman reported that the catfish registry in the USA was conceived as an 'ancestral breeding catalogue' (Dunham and Smitherman 1984) to remove widespread frustration among culturists and researchers stemming from lack of information on the origins and interrelationships of commercial strains. It has been very successful and would be an excellent idea for tilapias.

Estimation of Genetic Parameters and Evaluation of Culture Performance

Dr. G.W. Wohlfarth

The information presented by Wohlfarth et al. (in press) and Hulata et al. (in press) describes the work done at the Dor Station comparing different strains of *Oreochromis aureus* and *O. niloticus*. In summary, there was considerable genetic variation within each species, i.e., among the 'isolates' of each species. Therefore there is a clear need to test different isolates and their adaptation to given culture environments. There is a possibility of genotype x environment interaction and different strains or 'isolates' must be evaluated in the culture environments for which they are being developed.

The sample size used and number of tests performed at Dor were small, but it appears that both within *O. aureus* and *O. niloticus*, the isolates currently in commercial use ranked lowest in comparisons among three or four isolates tested. This indicates that there is room for improvement (which is good news for tilapia geneticists!).

To explain these results, it must be understood that, in Israel, *O. aureus* is endemic whereas all cultured *O. niloticus* stocks were introduced. The *O. niloticus* isolate in most common commercial use derives from the introduction of a small number of fish (nine females and two males) from Ghana. Its performance may have deteriorated due to inbreeding, genetic drift or loss of beneficial alleles. The other *O. niloticus* isolates in the comparison came from larger numbers of founders and have a shorter history of domestication. There is a lesson here. When making an introduction, ship an adequate number of fish and as far as possible equal numbers of males and females.

For *O. aureus*, three isolates have been studied: 1) a commercial hatchery stock, maintained for several generations at Dor, 2) another local stock from an isolated irrigation reservoir, left undisturbed for many years and 3) a sample of wild fish from Lake Manzallah, Egypt. The commercial stock was ranked the lowest in performance.

In Israel, the most important commercial trait is the ability of *O. niloticus* and *O. aureus* parental stocks to produce near-100% male hybrid F_1 progeny. There was therefore a move to

select from the tilapias available in Israel (*O aureus* and the *O. niloticus* introduced from Ghana and Uganda) to produce uniform parental stock that give high percentages of male hybrid progeny. Electrophoresis was used to determine genetic variation in the available stocks (Wohlfarth and Hulata 1983) [see also p. 50 - Editor]. The *O. niloticus* stock from Uganda was found to be highly variable. It was discarded for production purposes. By contrast, the Ghana fish showed more uniform electrophoretic patterns. This became the preferred stock for hybridization purposes.

For *O. aureus*, a high level of genetic variation was indicated by electrophoretic patterns and efforts were made to eliminate this. Breeders sent blood samples to the electrophoresis laboratory at Bar Ilan University and received advice on which fish to keep and which to discard in order to produce a more uniform stock (Mires 1977; Galman et al., in press a).

It is extremely important to have reliable methods for evaluating the culture performance of different groups of fish. For common carp (*Cyprinus carpio*), communal testing has been shown to be an efficient method for comparative evaluation (Wohlfarth and Moav 1985). This method has been applied by other researchers working with catfish and salmonids (Dunham et al. 1982; Gjerde et al. 1983). It is a *convenient* method; for example with a large number of genetic groups, comparative evaluation using separate testing would require a huge number of ponds, bearing in mind pond-to-pond variation and the need for replicates.

There are two problems with communal testing of different genetic groups of tilapias. First, there is the need to mark fish efficiently and without undue damage. This has not been solved completely; although a variety of techniques exist, e.g., spine clipping (Rinne 1976). Second, the possible effects of interaction, such as competition for food, between the communally stocked groups. As a result of interactions, results from communal testing may differ from those obtained in separate testing and, of course, separate *culture* of the best genotype is the ultimate objective.

For evaluation of this technique, a series of tests involving communal *and* separate testing is recommended. The data can be presented as a regression of differences in growth in communal and separate testing. This requires considerable effort and time. A trial in 15-20 ponds gives only a single point for the regression analysis. This approach has been used in Israel and by McGinty (1987) in Puerto Rico. It is important that such efforts continue. International cooperation could reduce the burden of testing. It would be very valuable to form an international research group so that the results of those involved in separate and communal testing could be pooled [see p. 74 - Editor]. At least 10 or 15 major experiments are required, as was done with the common carp in Israel (Moav and Wohlfarth 1974). This is a huge task for a single research group as it ties up facilities and hinders other research. This is particularly serious when the breeding and growing seasons are restricted by climate, as they are in Israel.

A further important factor is the variation in initial weight amongst the fish under test. The procedure used by Wohlfarth and Moav (1985) to correct for initial weight differences in common carp may or may not be necessary with tilapias. It cannot be 'extrapolated' for use with other species unless a regression of weight gain on initial weight, under conditions of communal testing, is demonstrated.

Discussion

Dr. Pullin commented that the reports of possible loss of genetic variation in *O. aureus* in Israel gave further weight to the need to conserve natural genetic resources, as these are the sources of additional genetic variation. He added that supplying tilapias to others is a major responsibility because the recipients are getting the results (intentional or otherwise!) of the breeding objectives and hatchery practices of the suppliers. Israel, for example, has supplied *O. aureus* and *O. niloticus* to many countries, as have certain western universities.

Dr. Smitherman felt that it was inappropriate to call the Israeli experience with electrophoretic checking of broodstock a "misuse". It was used as a tool with, presumably, the objective of producing two inbred populations of *O. aureus* and *O. niloticus* to be crossed. The technique clearly worked. However, it is patently undesirable for such parental stocks to then be supplied to others as single-species broodstocks for production purposes. Dr. Smitherman added that he had heard while attending the First International Symposium on Tilapia in Aquaculture,

Nazareth, 1983, that some Israeli farmers were using F_1 *O. niloticus* x *O. aureus* hybrids as broodstock. He asked for clarification on this, particularly the question of whether reduced viability by inbreeding of parental stocks had prompted farmers to begin this practice.

Dr. Hulata responded that the loss of genetic variation in Israeli broodstocks was not really a result of the use of electrophoresis. The Israeli methods of breeding tilapias tend to push farmers towards using relatively small numbers of broodstock anyway. In the future, it will be no use collecting material of wide genetic variation from the wild if the broodstock management practices of culturists cause losses of variation over successive generations. The tendency of some Israeli farmers to use F_1 hybrids as broodstock is because of their higher fry production, and was made possible by the introduction of sex reversal technology to produce all-male progeny. They have taken the narrow and potentially dangerous view that as long as the broodstock give high fry production, which can then be treated with hormone to produce about 99% males, other genetic characteristics do not matter.

This is a mistaken view. Farmers in many countries may not need to use hybrids at all for production purposes. They should use their best single-species strains and use sex reversal techniques to produce all-male progeny. In Israel, the *O. niloticus* x *O. aureus* cross was developed initially because it was the only known method for producing > 95% male progeny in commercial quantities. With the advent of sex reversal technology the hybrid is still used for production purposes in Israel, chiefly because of its cold tolerance attributes, derived from the *O. aureus* parent. *O. niloticus* is more cold-sensitive. *O. aureus* is not cultured as a single species in Israel because it is very difficult to harvest: the fish burrow into the pond mud. The hybrid combines the best traits of both parents. Cold tolerance is not an important trait in most tropical countries and for these *O. niloticus* is fast becoming the species of first choice. However, cold tolerance may be an important attribute for the mid- and higher-altitude regions of Africa and for subtropical countries.

Dr. Smitherman asked whether any data are available on the performance of the progeny of F_1 broodstock.

Dr. Hulata said that in one comparison, sex-reversed F_2 fish performed worse than F_1's and had a wider variation in weight at harvest, as expected from genetic theory (Hulata et al., in press). Dr. Hulata advised strongly against the use of F_1 hybrids as broodstock and F_2's as production or crossing material. There is no sound reason for such practices.

Dr. Smitherman said that experiments performed at Auburn University confirmed Dr. Wohlfarth's statement that the ranking of groups is the same in communal and separate testing. The same applies to the McGinty (1987) results from Puerto Rico (here the comparison between red and normal-colored fish was much easier than tagging fish of similar appearance). Dr. Smitherman's view was that the true performance of a given strain could best be determined in well-replicated tests in separate ponds.

Dr. Pullin commented that pond to pond and even cage to cage variation could be so high as to make even replicated separate testing a difficult procedure to perform. He referred to experience in using separate testing in cages in Laguna de Bay, Philippines, in a cooperative project between the Marine Science Institute of the University of the Philippines (UPMSI) and ICLARM. A BFAR-UPMSI-ICLARM team is now using communal testing of tagged fish in different farm environments and comparing further the use of communal and separate testing in experimental tanks. Dr. Pullin said that it was too early to assess the results but that he expected that communal testing would emerge as the preferred method. If this ranks performance reliably, it can be used to *indicate* the better strains for further testing. Communal testing by different farmer cooperators, stocking different groups of tagged fish communally with the production stock, could allow the performance of a range of genetic material to be tested in many different farm environments. There is wide farm-to-farm environmental variation as there is from pond-to-pond, but communal testing then becomes a strength. Dr. Pullin said that interaction between communally stocked groups is a problem, but doubted that the disadvantages from this were greater than those of using large numbers of ponds, tanks or cages for replicated separate testing in which unit-to-unit variation is always a problem.

Dr. Smitherman agreed that this was an attractive approach but cautioned that stocking densities should be carefully controlled. The most accurate data are still to be got from separate testing on-campus, but on-farm communal testing should give useful indications.

Dr. Guerrero asked whether Dr. Wohlfarth felt that standard methods could be developed to compare the performance of different tilapias at different locations - for example, Israel, Asian and African countries - bearing in mind the wide differences in climate, culture systems and management.

Dr. Wohlfarth replied that the beauty of using communal testing is that it removes the need for standard methods. All the tested groups share the same environment. Indeed it is the 'nonstandard' nature of the culture environment that then makes the data so interesting, especially under farm conditions. Good on-farm performance is the objective. With communal testing, farms become, in effect, experimental facilities. However, to use this 'wonderful' technique it is essential to devise a reliable methodology.

Dr. Pullin agreed and said that this is what the Philippine group is now doing; using tilapia breeds already available in the country *before* launching into more extensive tests with new material to be imported from Africa.

Dr. Nugent asked for advice from those present on the future maintenance and development of 'Ivory Coast strain' *O. niloticus*.

Dr. Smitherman advised that it be kept for future investigations.

Dr. Wohlfarth recommended its continued use for production and further investigation and pointed out that there was as yet no data to indicate whether its performance under Ivorian conditions could be judged good or bad.

Dr. Pullin added that a strong selection program in the Côte d'Ivoire on this strain of rather mixed history could give a positive response.

Dr. Hulata commented that the 'Ivory Coast strain' is being reassessed in Israel, along with other material, because a recent introduction to Israel directly from the Côte d'Ivoire may be different from the fish assessed previously (and discarded because of incompatibility and poor fry production in attempted hybrid crosses with *O. aureus* and *O. urolepis hornorum*). These breeding problems were the only negative features of the 'Ivory Coast strain' found by Israeli researchers and this could be country-specific to Israel.

Dr. Hulata suggested that the ϕ' index devised by Moreau et al. (1986) and further used by Pauly et al. (in press) could be incorporated in culture performance evaluation. The ϕ' index, if proven to be a reliable parameter for comparing different strains, could mean that comparative evaluation could be somewhat centralized and then followed-up by on-farm trials.

Dr. Lester emphasized the importance of genotype x environment interaction. This means that whereas an index of growth performance like ϕ' can be broadly indicative of the value of a breed in the test environment, breeds still have to be tested under the actual culture environments used by farmers.

Mr. Msiska said that cold tolerance is a very important trait for tilapia culturists in many African countries and asked whether there were any data comparing the cold tolerance of the Egyptian strain of *O. niloticus* with that of the Israeli *O. niloticus* x *O. aureus* hybrid. He felt that production of hybrids is inappropriate for most African tilapia culture.

Dr. Hulata responded that no such comparisons had been made either between *O. niloticus* and hybrids or within different *O. niloticus* strains available in Egypt. He cautioned against putting too much emphasis on a single production trait (as had been done in Israel for all-male hybrid fry production). It is important to look at all the attributes needed for a given situation and then develop the best breeds to perform well in that situation.

Dr. Wohlfarth said that results in Israel show that in general a good all-male *O. niloticus* x *O. aureus* hybrid gives better first-year growth than a mixed sex pure species strain. There may be some heterosis involved or it may be just the all-male growth superiority. However, for second-year growth after overwintering the fish and culling females, all-male populations of hybrids and single species show similar performance: if anything, the single-species populations are superior in growth to the hybrids.

Session IV. Gene Banks and Culture Collections

Gene Banks: Cryopreservation as a Tool

Dr. B.J. Harvey

We have considered already the wide range of tilapia genetic resources, their conservation and utilization. Cryopreservation is a potentially useful and relatively inexpensive tool. The application of cryopreservation to tilapia culture has been discussed by Harvey and Kelly (in press). There are a number of genetic goals, the pursuit of which can be assisted by cryopreservation/sperm banks: hybridization; avoidance of inbreeding depression; selective breeding programs; gynogenesis; domestication and conservation.

This workshop is really concerned with the last of these - collection of gametes from wild populations, their conservation and use in domestication. Milt can be collected from a wide range of known founder stocks and stored. The arguments for such gene banks are the same as those for seed banks in crop breeding.

The milt collection and storage techniques are simple. A simple diluent is added to the milt and the sperm can then be frozen in a matter of seconds. The freezing rate must be controlled, but this can be done easily by the design of the container. Storage in liquid nitrogen can be regarded as indefinite.

The cost and practicality of milt storage and shipment have been recently improved by the development of 'dry shippers' (Union Carbide Corporation, Cryogenic Equipment Department, 4801 West 16th St., Indianapolis, IN 46224, USA). A dry shipper is a canister, about the size of a large thermos flask, that contains an absorbent material. This material is cooled, i.e., charged with liquid nitrogen at a convenient source. The material soaks up the liquid nitrogen so that there is no liquid moving around in the container during shipment. The material remains at or close to the temperature of liquid nitrogen for up to three weeks after charging - depending upon ambient conditions and the number of times that it is opened. Dry shippers have been taken on commercial flights as cabin baggage for transportation of cattle embryos. Therefore, provided that a shipper can be charged with liquid nitrogen, say at a cattle Artificial Insemination (AI) center, then tilapia sperm could be collected and frozen in the field over a period of at least a week.

The main limitation with cryopreservation as a tool for fish gene banks is that at present it is not possible to freeze the eggs or embryos of any fish, although research efforts are continuing. Therefore fish gene banks involving cryopreservation must be, for the foreseeable future, haploid gene banks.

Discussion

Dr. Pullin agreed with Dr. Harvey on the difficulties of freezing fish eggs and embryos and referred to work with marine flatfish (Pullin 1975; Pullin and Bailey 1981). On the question of tilapia sperm banks, Dr. Pullin felt that only a small number of researchers would use these if they were established now. Most applied researchers and culturists might prefer initially to work with live fish.

Mr. Nugent said that perhaps sperm banks would be one way of preserving genetic resources that may become extinct in nature.

Dr. Villwock agreed that sperm cryopreservation is a very useful technique. It facilitates the conservation of genetic variability. The FAO Expert Group on Conservation of Genetic Resources of Fish has recognized this (FAO/UNEP 1981). Even if eggs and embryos cannot be preserved, sperm preservation is better than no preservation.

Dr. Harvey emphasized that whereas it is preferable to collect and ship live fish rather than fish sperm, shipping the latter *is* feasible and relatively inexpensive for those who want to do it. For populations under threat of extinction and for which the logistics of live fish shipment are difficult, sperm shipment and storage could be very useful. The thawing of frozen semen (in plastic straws) and its use in artificial fertilization are very simple techniques.

Dr. Pullin said that cryopreservation of bull semen has revolutionized cattle breeding. There are AI centers in most countries, including third-world countries. Dr. Pullin said that he had once kept marine flatfish sperm in storage at the AI unit of an experimental farm operated by the Board of Agriculture and Fisheries of the Isle of Man. Perhaps the AI centers of developing countries, particularly those in Africa, could assist with provision of liquid nitrogen and storage facilities for tilapia sperm.

Dr. Smitherman supported strongly the idea of starting tilapia sperm banks. He mentioned that cryopreservation of sperm will be used to assist in the maintenance of catfish germplasm collections at Auburn University. It is expensive to maintain effective breeding numbers of live populations for a large number of genotypes. For a 2-line cross, one line can be kept as live fish and the other banked as sperm. The best performing catfish at present is an interspecific cross, blue catfish x channel catfish. Since catfish eggs can be stripped, sperm storage would be a useful tool in making such crosses.

Dr. Wohlfarth suggested that semen collected and frozen in the field could be brought back to a laboratory for electrophoretic analysis and then stored/used for breeding schemes or discarded, according to the results.

Dr. Harvey welcomed this suggestion.

Dr. Lester said that one problem with this is that in sperm there is a lack of activity of a large proportion of the genome. Sperm as a tissue provides far fewer loci for electrophoretic studies than, for example, heart, liver and muscle.

Dr. Hulata asked whether immunological methods could be used to characterize sperm samples.

Dr. Villwock said that this is certainly worth investigating.

Tilapia Broodstock Collections in the Philippines

Mr. M.M. Tayamen

The National Freshwater Fisheries Technology Research Center (NFFTRC) of the Philippine Bureau of Fisheries and Aquatic Resources (BFAR) has the largest collection of tilapia broodstock in the Philippines. Broodstock of various species and strains are maintained at certain other institutions, notably Central Luzon State University (CLSU), which is adjacent to the NFFTRC, and the Freshwater Fisheries Station of the Southeast Asian Fisheries Development Center (SEAFDEC). This presentation concentrates on the stocks held at the NFFTRC which has been designated as the National Broodstock Reference Center. Broodstock improvement at the NFFTRC is undertaken by the Technology Verification Unit (TVU).

Broodstock of *Oreochromis niloticus* termed 'Israel' (BFAR 83), 'Singapore' (BFAR 82) and 'Taiwan' (BFAR 84) strains, *O. aureus* from Taiwan (previous origin unknown) and red tilapias are all maintained in the TVU [see p. 42 for details of origins - Editor]. The year numbers for *O. niloticus* refer to the year of first production of the founder stock. The TVU keeps the original broodstock in 600-m^2 breeding ponds termed 'NP' of which there are 30. The F_1 progeny from the NP are grown to about 50 g, sexed and then grown on by the Fish Seed Production Unit (FSPU) in 1,200-m^2 rearing ponds (termed RP), of which there are 16, and 'stock' ponds (SP) of about 4,500 m^2, of which there are 12. These then produce F_2 fingerlings for distribution to farmers by the Extension Unit. Broodstock are also distributed to BFAR satellite stations directly from the TVU (Fig. 25). There are 33 BFAR farms distributed throughout the country, of which 24 have received NFFTRC broodstock. The most widely distributed strain is the Israel strain.

The original founder stocks of *O. niloticus* - BFAR 82, BFAR 83, BFAR 84 - are still intact and maintained in separate ponds. These will be kept for comparison with new introductions.

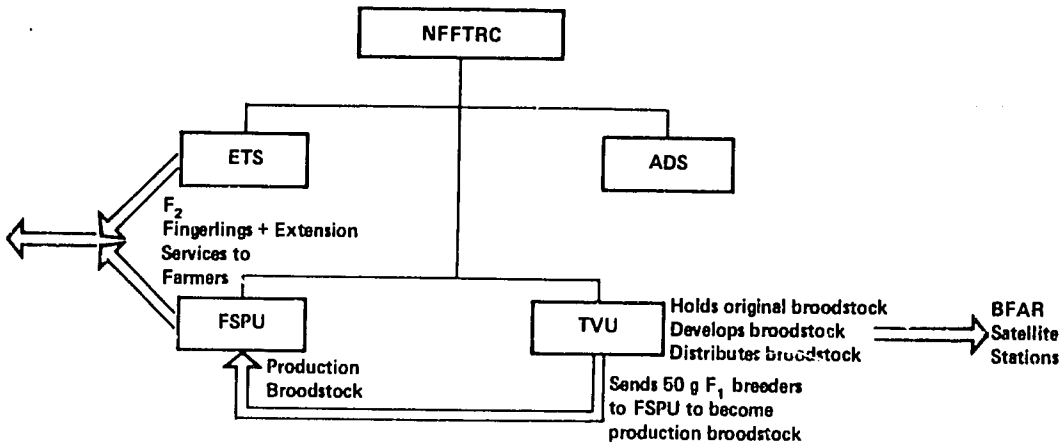

Fig. 25. Diagram showing the various units of the National Freshwater Fisheries Technology Research Center (NFFTRC) of the Philippine Bureau of Fisheries and Aquatic Resources (BFAR), Muñoz, Nueva Ecija, Philippines. ADS = Administrative Services; ETS = Extension Training Services; FSPU = Fish Seed Production Unit; TVU = Technology Verification Unit.

Wild fish are screened out completely. Backcrosses between offspring and parental stocks are prevented by draining the culture collection ponds every four months to remove fry/fingerlings before they mature.

Discussion

Dr. Smitherman commented on the age of the original stocks (BFAR 82, 83, 84) and the need to 'turnover' these populations, perhaps rather soon.

Mr. Tayamen agreed and said that new founder stocks will be obtained to develop a wider broodstock collection, in the hope of developing breeds for a variety of culture systems (ponds, cages, rice-fish farming, etc.). The existing stocks may deteriorate.

Dr. Smitherman said that the existing stocks can be maintained and may not deteriorate if an appropriate management policy is followed; for example, to avoid inbreeding. [See Appendix II on maintenance of effective breeding numbers - Editor].

Further Discussion

Dr. Lester asked whether any of the developing countries of Asia and Africa represented at the workshop were planning to establish culture collections of tilapias like those existing or being established in, for example, Israel (Dor Station), the USA (Auburn University, Alabama), and the Philippines (CLSU/BFAR)?

Mr. Msiska replied that the Department of Fisheries in Malawi has established a collection of indigenous tilapias at the Domasi Fisheries Station, near Zomba. They are maintained in earthen ponds. The main problems are bird predation and avoidance of cross-contamination between different populations.

Mr. Tayamen added that bird predation is not a serious problem in the Philippines. However, fish predation and cross-contamination are potential problems. Water supplies to the culture collection are screened and also pass through sand and gravel filters. The screens are checked twice daily.

Dr. Smitherman referred to plastic netting developed to keep birds off crops. This can be used to cover ponds. Tilapia culture collections in small ponds or concrete tanks should be covered with netting anyway - not only to keep out fish dropped by bird predators but also to prevent tilapias jumping from tank to tank.

Mr. Balarin reported that Baobab Farm Ltd., Mombasa, Kenya - a commercial farm - maintains a culture collection of about 12 species of tilapia and up to eight 'strains' of *O. niloticus*. These are all kept in separate covered tanks.

[Collections of live tilapias are maintained at various institutions - notably Auburn University, Alabama, USA; the Dor Station, Israel; The Institut des Savanes (IDESSA), Bouaké, Côte d'Ivoire; Gottingen and Hamburg universities, Federal Republic of Germany; the University of Liège, Belgium, and the Institute of Aquaculture, Stirling University, UK - Editor].

Dr. Hulata said that in Israel the general practice is to propagate fish only from tagged broodstock. Moreover, fish used in breeding schemes and culture collections are always spawned indoors in concrete tanks, not in open ponds. This ensures that at least the reference stocks are of known identity and from known parents. Only for multiplication of fish for use by commercial breeders is spawning done in outdoor ponds.

Dr. Pullin referred again to the need for an International Tilapia Strain Register. This would need strict criteria and standards for strain documentation. The claims of the private sector for the performance of certain 'strains' need careful scrutiny. How is this done for catfish and salmonids?

Dr. Smitherman said that strain registries must deal with research stocks (for which relatively good information is usually available) and commercial stocks (for which the only information is usually that supplied by the farmer). The origins and lineage of commercial stocks can often be traced, but farmers' claims for their performance can only be investigated by rigorous comparative testing. This is difficult and expensive. A central site or a network of testing sites would be required; recognizing the problem of genotype x environment interaction. Despite such difficulties, a start should be made on a tilapia strain registry, with standards and recommendations for testing procedures.

Dr. Pullin said that a simple check on the identity of stocks would be a useful first step.

Dr. Lester felt that a blood group test-kit, as projected by Dr. Villwock's Hamburg research group, offers the best prospects for simple checks on identification in the field. Electrophoresis and multivariate analysis of morphometric/meristic data are much more expensive and laborious and probably less precise.

Mr. Balarin said that some commercial suppliers already maintained careful checks on stock shipments. Baobab Farm Ltd. insists on 'letters of no-objection' from local and/or national authorities before shipping tilapias to recipients in Kenya or other countries. Perhaps copies of such letters and photographs of the parental stocks could be lodged with an international registry. This would at least help to document the current situation and keep records of shipments.

Dr. Villwock agreed that this would be a useful step.

Dr. Wohlfarth said that these are all good ideas. Those present at the workshop should take the lead *now* by sending details of their stocks to ICLARM. The format can then be assessed and requests made to other institutions not represented here for their inputs. It is important to make a start and those present at this workshop are the best placed to make that start.

Dr. Villwock agreed.

Dr. Pullin welcomed the suggestions that ICLARM take responsibility for receiving such information and developing a registry. ICLARM is an international, nongovernmental, nonprofit research center constituted and funded like the International Agricultural Research Centers (IARCs) of the Consultative Group on International Agricultural Research (CGIAR).

For a registry of data on natural populations and preserved specimens, the Zoological Museum, Department of Ichthyology, University of Hamburg, would be a good choice.

Dr. Villwock thanked Dr. Pullin and encouraged those present to send information to ICLARM and Hamburg, so that a start can be made.

Dr. Hulata said that guidelines are first required for formatting the information. These can probably be taken from the trout and catfish registries.

Dr. Villwock agreed, but still encouraged an immediate start to supplying information. A standard procedure will be necessary for collecting and preserving new specimens.

Dr. Smitherman said that the trout register had been prepared by Dr. H. Kincaid (1981). The first step is to ask the following questions for a given stock: 1) origin? (as far back as this can be traced and 2) for the breeding population, a. number and sex ratio of the founder stock(s)? b. methods used for replacement or transfer. These are the most basic questions. Beyond these, documented information on performance traits should be requested - whether derived from scientific study or not and whether published or not.

Session V. General Discussion Leading to the Formulation of Recommendations

Chairman: Dr. R.S.V. Pullin

Documentation and Conservation of Tilapia Genetic Resources

Natural populations

After much discussion, a list was drawn up of important sources of tilapias used in aquaculture or of potential future use (Table 9). This is not to be regarded as an exclusive list, but reflects the opinions of those present. Species are listed in approximate order of their importance in aquaculture within the genera *Oreochromis, Sarotherodon* and *Tilapia*.

Dr. Villwock recommended the establishment of reference collections of preserved material. The collections should include, with the specimens, full details of their origin, date of capture, condition, etc. and morphometric/meristic data. Photographs of fresh-killed or live material should also be included. If any immunological or electrophoretic studies were done on the specimens, these data should also be recorded. This would constitute good documentation.

Regarding conservation, the wild locations containing undisturbed natural populations should, as far as is possible, be protected and kept undisturbed. Culture collections of live fish and gene banks of cryopreserved sperm should be established both to guard against loss of natural genetic resources and to make those resources available to researchers.

Dr. Marshall asked whether morphometric data from preserved material could be compared with that from fresh material. In other words, could measurements from new material be compared with those taken from museum collections?

Dr. Lester said that photographs of museum specimens and new material could be compared by shape analysis. If some meristic data (especially gill raker counts) could be provided as well, this could be a useful tool for studying changes in populations and the identity of material.

Dr. Pullin cautioned that long-preserved specimens can shrink or become deformed, but perhaps correction factors could be worked out for this.

Dr. Thys van den Audenaerde said that museum specimens often had folded fins or other characters that photographed rather poorly.

Dr. Villwock agreed and said that the way to avoid this was to anesthetize specimens before preservation and then to add the preserving medium slowly. If this is done, the fins remain extended.

Dr. Hulata suggested that Dr. Villwock prepare a protocol for the collection and preservation of new specimens and circulate this to interested field researchers.

Dr. Villwock agreed to do this and said further that the University of Hamburg would be prepared to act as the registry for information on museum collections and reference data on wild stocks.

Dr. Pullin welcomed these suggestions and said that standardized protocols are needed for sampling populations and collecting data in the field.

Dr. Wohlfarth suggested that the collection of specimens for preservation and the collection of live material (frozen sperm and fish) could be done together.

Dr. Marshall agreed and suggested that tissues be sampled for electrophoretic analysis at the same time.

Dr. Pullin agreed that this would be desirable but mentioned that the logistics of collecting live fish, tissue samples and sperm (availability of dry ice or liquid nitrogen) would be difficult in much of Africa.

Table 9. Suggested locations in which undisturbed or relatively undisturbed populations of tilapias that are important, or potentially important, for aquaculture may be found and should be conserved.

Species	Best location(s)	Additional location(s)	Remarks
Oreochromis niloticus			
O.n. niloticus	Sénégal; the Nile system and Egyptian lakes	The Volta system, Ghana; the Niger system, Burkina Faso, Mali and Niger, for example, the 'mare aux hippos', Burkina Faso; Lake Chad, Cameroun, Chad, Niger and Nigeria	The Sénégal and Nile stocks are least disturbed; others mentioned are at risk of interbreeding with fish from adjacent aquaculture activities– for example, introductions from Bangui, Central African Republic (origin/Côte d'Ivoire), are now in the Logone River which drains to Lake Chad; Ivorian fish may also reach the Niger and Volta systems
O.n. vulcani	Lake Turkana (Lake Rudolf) Kenya–the type locality is crater lake A; crater lake C is probably also undisturbed	–	The only location for this subspecies
O.n. eduardianus	The western Rift Valley Lakes–Lake Albert, Uganda-Zaïre; Lake Edward, Uganda-Zaïre and Lake George, Uganda	–	Probably Lakes Edward and George are the better locations
Oreochromis aureus	The Nile Delta Lakes, Egypt; the Sénégal system, Sénégal and the middle Niger system, Mali, Niger	–	The Sénégal and Egyptian populations are probably the least disturbed
Oreochromis spilurus			
O.s. niger	The Tana River; lower reaches	–	This subspecies now seems to have disappeared as a pure subspecies from the upper Athi, Kenya (E. Trewavas and R.H. Lowe McConnell, pers. comm.)
O.s. spilurus	The lower Athi, Kenya	–	The only known location, but even here it hybridizes with *O.s. niger*
O. placidus	The lower Shire system, Malawi	–	Coexists with *O. mossambicus*
Oreochromis shiranus			
O.sh. shiranus	Lake Malawi and the upper Shire, Malawi and Mozambique	–	The only known locations
O.sh. chilwae	Lake Chilwa, Malawi	–	The only known location
Oreochromis andersonii	The Kafue system, Zambia; the upper Zambezi, Zambia/Zimbabwe; the Okovango swamp, and river and Lake Ngami, Botswana	–	Kafue and Zambezi stocks may come into contact with *O. niloticus* and *O. aureus* escapees from farms

Continued

Table 9. Continued

Species	Best location(s)	Additional location(s)	Remarks
Oreochromis macrochir	The Okovango swamp, Botswana; the Upper Zambezi, Zambia/Zimbabwe; the Kafue system, the Bangweulu region and Lake Mweru, Zambia/Zaïre	–	The Botswana stocks are the least disturbed
Oreochromis mossambicus	Lake Sibaya and lower river reaches in Southern Africa	The Middle and Lower Zambezi	The South African stocks are probably the least disturbed; aquaculture adjacent to waters draining into the Zambezi may cause contamination of these stocks
O. saka *O. squamipinis* *O. karongae* *O. lidole*	Lake Malawi, Malawi	–	Pure stocks; the inmature stages are difficult to distinguish
Oreochromis urolepis			
O.u. urolepis	The lower Rufigi, Kingani and Mbemkuru and the Ruaha near its junction with the Rufigi Tanzania	–	
O.u. hornorum	The Wami River, Tanzania	Zanzibar?	The only known location(s)
Sarotherodon melanotheron	Coastal West African lagoons from Senegal to Zaïre	–	Widespread in this region; should not be confused with *Tilapia guineensis*
Sarotherodon galilaeus	Lake Chad, Chad and Cameroun; Lake Turkana (Lake Rudolf), Kenya, Lake Kinneret, Israel	Numerous locations throughout Sahelian Africa and north to Egypt	Widespread and probably little interbred with other species
Tilapia rendalli	The Okovango swamp, Botswana; the Kafue system, Zambia	Widespread in southern Africa	The Okovango and Kafue stocks are probably the least disturbed
Tilapia rendalli	Lake Chad, Chad and Cameroun; Lake Turkana (Lake Rudolf); Kenya; Lake Albert, Uganda, Zaïre at Yangambi	Widespread through west and Sahelian Africa and north to Egypt	Widespread and probably little interbred with other species

Mr. Balarin and Dr. Lowe-McConnell mentioned the importance of specimens in African museum collections and African archival material. Some of this material is becoming increasingly at risk as the institutions holding it have insufficient funds to catalog and maintain it properly. It was further recommended that, when new specimens are collected for reference collections, replicate material be kept in museum collections, a central registry and in collections in the source countries.

Dr. Pullin asked whether those present felt that international bodies such as the International Union for the Conservation of Nature (IUCN) or the United Nations Environment Programme (UNEP) might take an interest in this work for the conservation of tilapia genetic resources.

Dr. Lowe-McConnell mentioned the interest of the IUCN in updating the Red Data Book on endangered species.

Dr. Thys van den Audenaerde said that IUCN established a subcommittee for the protection of fish species, about 10 years ago.

Dr. Villwock referred to the FAO/UNEP consultation on fish genetic resources (FAO/UNEP 1981) in which liaison with IUCN and other bodies is recommended. Again, however, it was recommended that a *start* needs to be made on tilapia conservation by those present at the workshop.

Mr. Balarin reported that IUCN has been active in crocodile conservation by sending a questionnaire to farmers, compiling the information received and following up with field visits. This study is still continuing, funded in part by the EEC. Of course there are only a small number of crocodile farmers compared to fish farmers.

Dr. Pullin said that the key question was whether IUCN would be interested in conservation work for an *applied* objective (fish farming) as opposed to a pure objective (nature conservation). Perhaps IUCN would not appreciate the importance of the few tilapias used for culture as opposed to the many tilapias that are part of 'wildlife.'

Dr. Thys van den Audenaerde said that IUCN is primarily interested in endangered species, irrespective of their future commercial uses. IUCN probably has insufficient funds and staff to tackle problems like conservation of tilapia genetic resources.

Dr. Harvey agreed and said that IUCN has shown 'polite' interest in fish gene banks but has as yet offered no support.

Dr. Coche added that with respect to control and documentation of fish introductions and transfers, FAO/EIFAC (European Inland Fisheries Advisory Commission) and ICES (International Council for Exploration of the Sea) have jointly developed Codes of Practice (Turner 1987) which are now being studied for adoption by the Committee of Inland Fisheries of Africa (CIFA), the Comision de Pesca Continental para America Latina (COPESCAL) and the Indo-Pacific Fishery Commission (IPFC).

Farm stocks

Dr. Pullin asked for suggestions on further documentation and conservation of farm stocks, including those in use in Asia, such as the Chitralada strain of *O. niloticus* in Thailand.

Dr. Villwock said that farm stocks should be included in the reference collections and registry of descriptions suggested for wild stocks. This will then give a complete picture. Material from farm stocks should also be kept in live fish collections and gene banks.

Dr. Hulata added that some Israeli farmers are developing their own stocks and will probably continue to do so. Some stocks are better than others. Some have been evaluated under experimental conditions. However, not all farmers will be willing to donate material for reference collections and to supply live material for evaluation, particularly the latter. This probably applies to the private sector worldwide - some farmers will cooperate; others will not. It is clearly important to gather as much information and as many specimens as possible from farm stocks and to encourage all farmers to manage their stocks carefully.

Dr. Lester said that where specimens or live fish cannot be obtained, photographs or videoimages will suffice. These can be digitized and stored in a computer. A reference collection can therefore contain digitized photographic images. These can be mailed to interested parties.

Dr. Pullin agreed and said that shape analysis as mentioned by Brzeski and Doyle (in press) and Pante et al. (in press) is likely to become a powerful descriptive tool. It requires the use of a digitizer.

Dr. Smitherman asked for further comments on whether commercial farmers would really be willing to share information on the origins and performance of their fish; especially data on growth rates and feed conversions.

Mr. Balarin responded that Baobab Farm Ltd., Mombasa, Kenya, has been very open about supply of information and has encouraged the University of Stirling to perform electrophoretic analyses on their fish collection. He said further that Baobab Farm Ltd. has about 15 years of growth and feed conversion data from its fish but lacks funds to analyze these data.

Dr. Pullin summarized the discussion on farm stocks as confirmation that the most important stocks are to be found in successful tilapia culture industries, such as those of the Philippines, Thailand and Israel; in well-organized farms in other countries, such as Kenya and in university collections such as those at Auburn and Stirling.

Evaluation of Tilapia Genetic Resources for Use in Aquaculture

Dr. Pullin reported that he had discussed this topic with ICLARM consultant Dr. Trygve Gjedrem during recent tours of the tilapia culture industries of Ghana, Côte d'Ivoire, the Philippines and Thailand. Dr. Gjedrem's opinion is that the same approach that has been taken in Norway to improve cultured breeds of Atlantic salmon can also be taken with tilapias. The approach is summarized by Gjedrem (1985). It involves collection of wild strains from a wide geographical range; evaluating these for commercial performance traits and then devising a breeding scheme to select for improvement in the most important traits. Thereafter trials are done in different culture environments to assess genotype x environment interaction; although for the Norwegian salmon industry one improved breed was found to rank the best in farms all along the coast. Salmon cage culture is of course a much less variable culture system than the many forms of tilapia culture. Dr. Pullin said that he agreed with Dr. Gjedrem's opinion but that others may prefer different routes to genetic improvement.

Dr. Smitherman said that the approach suggested by Drs. Gjedrem and Pullin has worked well for catfish and should also work for the tilapias. There is still, however, a lot to learn about genetic variation in tilapias, particularly in their early growth characteristics. Nevertheless, there is obviously considerable scope for genetic gain. For strain evaluation *within* a species, communal testing or well-replicated separate testing should be carried out. For evaluation between species, communal testing may be complicated by interaction between the different species, but the rankings will probably be unaffected. The test environment and feeding practices should as far as possible mimic the farm environment (e.g., ponds, tanks, raceways or cages).

[For communal and separate testing, the inclusion of a uniform 'internal control line' (ideally a homozygous line or an F_1 cross between two homozygous lines) can be a good way of removing experiment to experiment variation. This idea was communicated by Dr. Roger Doyle, Dalhousie University - Editor].

Dr. Wohlfarth said that the term selective improvement really encompasses mass (individual) selection; family selection (as used by the Norwegians for trout and salmon) and cross-breeding, hybridization, etc. Moreover the term F_1 the 'first filial generation' should strictly be reserved for the first generation of a cross between two *different* genotypes and not used for, for example, the first generation of a new founder stock just brought into captivity.

Dr. Moreau gave a further explanation of the index of growth ϕ', devised by Moreau et al. (1986)

$$\phi' = \log_{10} K + 2 \log_{10} L_\infty,$$

where K and L_∞ are parameters of the von Bertalanffy Growth Equation as a means of comparing the growth characteristics of a wide range of tilapias.

The index was first applied to wild marine fishes and then to tilapias in open waters. ϕ' is normally distributed for tilapias in natural waters. The highest ϕ' values are for *O. niloticus* in Lake Turkana and Lake Kainji and the lowest (worst) values for *O. mossambicus*, e.g., in Lake Sibaya.

Within species, the coefficient of variation is less (about half) that for comparisons between species. The technique has now been extended to compare cultured populations (150 data sets) from different systems (Pauly et al., in press). ϕ' is again normally distributed for this set of populations and the coefficient of variation within species and within strains is low. ϕ' compares growth performance in different sets of conditions, not growth rate. It can therefore delineate species and strains with good growth performance even under conditions where the growth rates and thus growth curves are different. The use of the index ϕ' is still at early experimental stage. It would be useful to work on more data sets, employing multivariate analysis on the

Table 10. Values of the growth performance index ϕ' for various open water populations of *Oreochromis niloticus* and *O. mossambicus:* from Moreau et al. (1986).

Species/sex	ϕ'	Locations	Reference
O. niloticus	2.41	L. Alaotra	Moreau (1979a)
O. niloticus	2.36	L. Alaotra	Moreau (1979a)
O. niloticus	2.62	L. Mantasoa	Moreau (1979a)
O. niloticus	2.57	L. Mantasoa	Moreau (1979a)
O. niloticus	2.65	L. Itasy	Moreau (1979a)
O. niloticus	2.52	L. Itasy	Moreau (1979a)
O. niloticus	2.71	L. Mariout	El Zarka(1961)
O. niloticus	2.73	L. Mariout	Payne and Collinson (1983)
O. niloticus	2.44	L. Mariout	Payne and Collinson (1983)
O. niloticus	2.41	L. Manzala	Payne and Collinson (1983)
O. niloticus	2.58	Moussa Hydrome	Jensen (1957)
O. niloticus	2.58	L. Tchad	Blache (1964)
O. niloticus	2.88	L. Albert	Ssentongo (1971)
O. niloticus	3.11	L. Kainji	Petr and Kapetsky (1983)
O. niloticus	3.07	L. Nasser	Petr and Kapetsky (1983)
O. niloticus	2.77	L. Nasser	Payne and Collinson (1983)
O. mossambicus	2.22	L. Sibaya	Bruton and Allanson (1974)
O. mossambicus	2.05	L. Sibaya	Bruton and Allanson (1974)
O. mossambicus	2.47	Incomati Limpopo	Hecht (1980)
O. mossambicus	2.37	Incomati Limpopo	Hecht (1980)
O. mossambicus	2.36	Njele Dam	Hecht (1980)
O. mossambicus	2.41	Winter Dam	Hecht (1980)
O. mossambicus	2.56	Loskop Dam	Hecht (1980)
O. mossambicus	2.47	Sheho Ngubu Dam	Hecht (1980)
O. mossambicus	2.46	Hartseespoort Dam	Hecht (1980)
O. mossambicus	2.70	De Hoop Vlei Dam	Hecht (1980)
O. mossambicus	2.33	Zeeloei Vlei Dam	Hecht (1980)
O. mossambicus	2.63	Loskop Dam	Hecht (1980)
O. mossambicus	2.51	Loskop Dam	Hecht (1980)
O. mossambicus	2.67	Doomdrai Dam	Hecht (1980)
O. mossambicus	2.46	Doomdrai Dam	Hecht (1980)
O. mossambicus	2.48	Luphaphe Dam	Hecht (1980)
O. mossambicus	2.39	Luphaphe Dam	Hecht (1980)
O. mossambicus	2.80	Egypt Ponds	Koura and El Bolock (1958)
O. mossambicus	2.71	Hong Kong	Man and Hodgkiss (1977)
O. mossambicus	2.59	Hong Kong	Man and Hodgkiss (1977)

environmental (*sensu lato*) factors that may influence ϕ'. However, the early indications are that, for a given strain, ϕ' is fairly constant and is a very useful index of growth performance.

Dr. Marshall commented that the poorly performing *O. mossambicus* of Lake Sibaya, South Africa, have always been assumed to suffer from food limitations. There are now new data sets available for *O. mossambicus* growth in hypereutrophic lakes. It would be interesting to compare the ϕ' values.

Dr. Moreau replied that some populations of *O. mossambicus* have higher ϕ' values than that of the Lake Sibaya population (Table 10).

Dr. Pullin suggested that this technique be applied to more data sets for single species, strains and hybrids from wild and cultured populations.

Dr. Hulata added that paired determinations of ϕ' on the same genotype in natural and culture conditions would be extremely valuable in the process of documenting and evaluating tilapia genetic resources.

Dr. Moreau responded that such work is now in progress for red tilapias and various hybrids. It is expected that the simultaneous use of ϕ' and P (another index; $P = \log_{10}(K.W_\infty)$, see Moreau et al. 1986) will help to identify the strains with the best growth performance.

Mr. Balarin said that after several years of 'selection' work at Baobab Farm Ltd. in which the largest individual *O. spilurus* were selected as broodstock, on the assumption that this would select for fast growth, it was realized that the selection had in fact been for 'aggressive behavior.' This was realized when some of the fish were transferred to very confined conditions (aquaria). Mr. Balarin cautioned that apparent genetic selection for growth may therefore be really

selection for behavioral traits. [But see Doyle and Talbot (1986) whose review downplays the possibility of selection for growth performance correlating with aggressive behavior - Editor].

Dr. Wohlfarth responded that *all* such selection and evaluation measures growth under a given set of conditions. The behavioral response is just one aspect of that set of conditions. Growth under a different set of conditions will be different.

Dr. Pullin referred to the techniques of growth rate estimation by scale circulus measurement developed at Dalhousie University (Kamonrat and Doyle, in press; Talbot et al., in press). This is a useful method for assessing the growth patterns of fish, particularly from specimens taken from farms and markets.

Dr. Smitherman summarized some recommendations on evaluation of tilapia genetic resources for use in aquaculture as follows:

The test environment should as far as is possible mimic the farm environment with regard to size and type, stocking density and nutrient resources. Correlations between rankings of different genotypes in different environments (i.e., genotype x environment interactions) should be estimated, in order to establish whether conclusions drawn from tests in one environment are valid for different environments. The test environment should be managed so that age, size, sex and maternal effects do not confound the experiments. If initial sizes of the fish under test are different, the relationship between initial and final size must be established and corrections made accordingly.

All evaluation trials should be adequately replicated. If replicate units are available, separately testing of genotypes can be used. If replicate units are unavailable or limited, communal testing should be used, but communal testing should only be used as the exclusive method after determining first the relationship between results from separate and communal testings. Critical recommendations should not be based on communal testing alone, until this relationship has been established. Testing data should be combined with data from other sources such as ϕ' values, multivariate analysis of field and farm data, etc.

A central data registry, for example at ICLARM, is needed to receive, collate and disseminate information on worldwide testing of tilapia genetic resources.

Culture Collections and Gene Banks

Mr. Balarin commented that perhaps live fish gene banks have the drawback that the fish will not only become adapted to but will also undergo natural selection for the gene bank environment, so that valuable genes for some culture environments may be lost. He said that high mortalities had occurred at Baobab Farms Ltd. among fish receiving feed containing aflatoxin. These fish were bred from a stock recently re-introduced from the University of Stirling. However, fish bred from *O. niloticus* stocks kept throughout at Baobab Farm Ltd. were tolerant to the same level of aflatoxin in a comparative trial. Thus there was a strong selection pressure for aflatoxin tolerance at the farm that is absent at Stirling University (which has higher quality feed) and the viability of the two stocks at the farm is now different. This is perhaps an indication that pampered aquarium stocks may eventually produce offspring that are not hardy in farm situations.

Dr. Pullin added that Mr. Balarin's point is very important. Most tilapia culture worldwide is in *ponds*; cage culture is the next most important system and tank and pen culture are of relatively minor importance at present. Perhaps live fish gene banks should involve ponds as well as tanks, though this will take a lot of space. The few limited live fish gene banks that have been set up, for example that at the Institute of Aquaculture, University of Stirling, rely mainly on aquaria for keeping their fish.

Dr. Smitherman said that broodstock management, i.e., maintaining adequate numbers of randomly mating broodstock and not discarding fish that do not grow so well in the gene bank environment, can minimize the problem. He suggested that differences in broodstock and hatchery management may have caused the large divergence between the Baobab Farm and Stirling stocks referred to by Mr. Balarin. If fish are kept well, mortalities are always low. Dr. Smitherman doubted that there would be any significant loss of valuable genes from well-kept fish collections, irrespective of the type of containment unit.

Dr. Pullin said that even if artificial selection is avoided, natural selection will still take place. There are always mortalities, especially in early life history stages: eggs, larvae and fry.

Dr. Lester said that there is no way of predicting whether useful genetic variation for a culture environment will be maintained over successive generations of fish kept in aquaria.

Dr. Hulata indicated that despite this potential difficulty, there is a 'trade-off' here. Fish kept in ponds are relatively inaccessible, difficult to observe and more liable to become contaminated (interbred with other stocks) than are fish kept in tanks and aquaria. Concrete tanks, aquaria and probably also cages are very similar environments. Natural selection to such environments may be a lesser evil than the management problems and risks of cross-contamination in pond collections.

Dr. Pullin recalled advice from Drs. Moav and Wohlfarth that an introduced stock should be taken through at least two generations in its new culture environment (to allow for natural selection) before making firm conclusions about its performance. Of course this is difficult if they all die from aflatoxin poisoning!

Dr. Wohlfarth added that the changes that occur inevitably when a wild stock is brought into captivity are summarized by the term 'domestication.'

Dr. Hulata said that more genetic variation will be conserved during this process of domestication if wild stocks are kept at different locations in different environments.

Dr. Harvey recommended that sperm collections be made parallel to live fish collections from the wild since, although cryopreserved sperm represents only half the genome, it certainly does not undergo any changes during storage in liquid nitrogen.

The discussion on this topic was concluded with general agreement that changes in 'banked' live fish populations are inevitable but that these can still provide a wealth of genetic material of value to the culture industry. The inevitability of some genetic change in live fish gene banks emphasizes the need for conservation of wild populations for future reference and utilization when needs arise.

Dr. Pullin summarized the discussion so far as presenting three categories of tilapia gene banks: wild populations conserved in their natural habitats; live fish collections; and cryopreserved sperm banks. He asked for comments on the relative importance of these, given the limited financial and staff resources available to establish and run tilapia gene banks.

There were divergent opinions on this. For example, Dr. Wohlfarth felt that milt cryopreservation was the most important and cost-effective approach.

Dr. Villwock favored live fish collections and sperm banks; because banked sperm of a given strain becomes less useful if the females of that strain become unavailable.

Dr. Pullin suggested that for the near-term benefit of tilapia industries in needy third-world countries, the establishment of live fish collections is the most important approach. However, this is expensive and requires rigorous standards of management and fish husbandry.

Dr. Smitherman urged that new culture collections be established and managed so as to preserve a wide range of genetic resources. Culture collections should be registered with an international registry, for which a body such as ICLARM should take responsibility.

Dr. Pullin mentioned that in a carp hatchery manual published by ICLARM (Jhingran and Pullin 1985) it is recommended that a new introduction (founder stock) be of around 2,000 individuals derived from a large number of parents and that the recipient hatchery should thereafter keep a minimum of 50 randomly breeding pairs. He invited comments on these recommendations [see also Appendix II - Editor].

Dr. Smitherman said that it is difficult to maintain effective breeding numbers, avoid brother-sister matings, etc., but that for tilapias this should be easier in the tropics (where year-round breeding is possible) compared to say Auburn University where broodstock must be overwintered. The figure of 50 randomly breeding pairs appears reasonable to keep the population turning over. However, spawnings will not be synchronous so perhaps more than 50 pairs will be needed for a replacement scheme.

All agreed that for long-term benefits, the tilapia genetic resources of Africa should be as far as is possible conserved in their natural habitats. However, the lack of appropriate institutional support for this, particularly in Africa, will be a major obstacle.

International Research Cooperation and Funding

Dr. Pullin led off the discussion by saying that the best approach to securing the necessary support for international research cooperation in tilapia genetics for development of tilapia culture is to aim at bringing together tilapia genetic resources and tilapia culture - in Africa, Asia and other regions. This requires interregional cooperation, especially between Asia and Africa, and much closer collaboration between geneticists and farmers. Training is also a very important requirement. It cannot be overemphasized that tapping the tilapia genetic resources of Africa must benefit the source countries and other African nations as well as recipients in other regions.

Dr. Marshall said that collecting fish is relatively easy for scientists in Africa. However, international cooperation is clearly required to improve culture technology in Africa and to bring to Africa some of the genetic techniques required - for example, sperm storage.

Dr. Pullin said that ICLARM now has an African Aquaculture Project Office in Malawi through support from the German Agency for Technical Cooperation (GTZ), GmbH. ICLARM is pursuing interregional research and training cooperation between Africa and Asia. FAO has organized study tours and training fellowships in Asia for Africans since the 1970s and also favors an interregional approach. The scope and nature of interregional cooperation clearly need careful planning, not least because some agencies and institutions involved in aquaculture research and development in Africa have a view that African farming systems and the African sociocultural environment are so different from those of Asia that Asian approaches and systems have little of benefit to offer Africa. This is definitely not ICLARM's view. ICLARM holds that, despite regional, national and local differences, the successes of Asian aquaculture have much to offer for adaptation to African settings. The key point is to study *African* farming systems first and then to see how aquaculture can be integrated into these as a profitable subsystem - not just to try to transfer crop- and livestock-fish systems directly from Asian models.

Dr. Lester asked for comments from African participants as to how high a priority is placed by national governments on fish genetic resources conservation and aquaculture research and development. This should indicate the extent to which African governments are prepared to allocate resources, including counterpart funding, for the programs under discussion.

Mr. Msiska said that African governments usually place their highest priority on fish production. At present this means usually capture fisheries rather than aquaculture. However, governments will support aquaculture research and development if they can be convinced that large benefits in production will follow quickly.

Mr. Ofori agreed and said that benefits, in terms of increased production, are essential for national governments to continue to support research programs. This can hinder research efforts. International cooperation and external funding are the best ways to avoid this problem and to sustain research for which the benefits are not so rapidly achievable.

Mr. Nugent said that few if any African governments could allocate their scarce resources to conservation of genetic resources, for which the rationale was a long-term possible benefit for tilapia culture. For most African governments, research must be directed at the immediate needs of food provision and livelihood improvement. There *is* interest in aquaculture development in Africa but this is far below interest in agriculture. It is doubtful therefore whether any African governments will allocate resources to the conservation and study of tilapia genetic resources. Perhaps the most that can be expected is that some governments with an interest in aquaculture, like that of the Côte d'Ivoire, might support small research projects designed to produce superior breeds for aquaculture. There is current research in the Côte d'Ivoire on developing improved strains of rice and coffee. However, there must be a 'pay-off' (and a fairly rapid one at that) to attract support. The Côte d'Ivoire has of course a rather long history of aquaculture research. Indeed the research station at Bouaké continued working for almost 30 years without any aquaculture industry developing in the country. Now that an industry is developing, the prospects for increased research government support are brighter. Ivorian universities and institutions like the Centre de Recherches Océanographiques are involved in aquaculture research. For research on genetic resources conservation, however, there are really no appropriate structures. This probably applies to most African countries.

Dr. Marshall said that initial studies and surveys for the conservation of natural genetic resources could probably be organized quite easily in most African countries with the assistance

of external experts and donors. Thereafter the success of conservation programs would depend upon the policies and attitudes of the African governments. These policies and attitudes vary greatly from country to country. It is fairly certain that no African country will allocate significant national resources to this conservation task or to establishing gene banks.

Dr. Coche agreed and said that the establishment and maintenance of live fish collections in Africa faces many problems. Facilities for this are not generally available. For example, FAO projects cater to fingerling production needs and there are no 'spare' facilities for genetics work.

The FAO regular program on aquaculture is really limited to development projects and has less scope for involvement, apart from occasional practical help. FAO projects, however, can be involved in collection of material for museums, etc. External funding for development and running of additional facilities in selected African countries is the only answer to this problem. The Aquaculture Development Coordination Programme (ADCP) is engaged in a Preparatory Assistance Project for UNDP entitled "Integrated Approach to Aquaculture Development in Africa." This will focus on: 1) short-term international training courses for aquaculture trainers, 2) establishing a network for applied research on small-scale rural fish farming in Africa, 3) establishing central services for coordination, information exchange and publication of materials, 4) information seminars and regional conferences and 5) assistance with national workshop and training on specialized biotechnical and nonbiotechnical (marketing, economics, socioeconomics, planning for investment) topics.

Mr. Chen Foo Yan said that in Asia as a whole, interest in tilapia is less than interest in carps and other organisms. However, there is now some interest in tilapia in China. Some Asian aquaculture systems, such as integrated farming, can be transferred from Asia to Africa. It is very valuable for African trainees to come to Asia to see Asian aquaculture. Last year several trainees came from Africa to China and a further six will come in 1987. This requires funding in the form of training fellowships. China may allocate some funding from its Technical Cooperation between Developing Countries (TCDC) funds to support local costs. For international travel, external donors are needed.

Mr. Balarin commented that aquaculture is assigned a low priority by most African governments simply because it produces so little cultured fish at present. The countries that benefit most from aquaculture at present (Table 11) (and which therefore may be more willing to support conservation and gene banks) are: Central African Republic, Côte d'Ivoire, Egypt, Kenya, Madagascar, Nigeria and Zimbabwe (if farm dam production is considered as aquaculture).

Mr. Ofori agreed that the best route to conservation and genetic resources research in Africa is to promote aquaculture development and thereby increase the importance of aquaculture.

Dr. Pullin said that ICLARM has a Network of Tropical Aquaculturists (NTAS) (Pullin and Paguio 1987). NTAS is a network of individual researchers, not institutions. Such networks are designed to help researchers make and maintain contact and to provide useful information, particularly on quantitative methods. This is done chiefly through a newsletter, 'Aquabyte'. Aquaculture genetics is one of three main themes of the NTAS membership - the other two being coastal aquaculture of molluscs and integrated farming systems. It is ICLARM's hope that the NTAS will encourage international cooperation in tilapia genetics research.

Dr. Lester said that international research cooperation on an individual basis is often extremely valuable and productive. Many laboratories in developed-country universities have staff who are keen to collaborate with colleagues in third-world countries and can assist in genetics research by cooperation in data analysis/interpretation, running electrophoretic gels, etc., usually with minimal expense involved. Such activities can sometimes be 'piggy-backed' onto existing research grants. The need for more substantial funding arises when international travel and training/exchange visits are called for.

Dr. Moreau said that the main requirement for increased international cooperation is leadership. It is easy to approach potential counterparts in many countries, but leadership is needed to mold this into a truly cooperative program. He recognized the leadership represented at the workshop from institutions experienced in international research cooperation such as Auburn University.

Dr. Pullin agreed but cautioned that the problems of securing adequate funding for such leadership are very great at present.

Table 11. A composite estimate of aquaculture statistics: Africa 1985 status (modified after Balarin, in press).

Country	Ponds (no.)	Area (ha)	Production (t/year)
Algeria			5
Angola			7 (500)
Bénin	113 – 155	6 – 2,000	5-9 (2,500)*
Botswana			0
Burkina Faso	32 – 50	11	114 (400)
Burundi	352	65	8
Cameroun	6,000 – 12,000	10 – 200	10 – 256
Capverde			?
Central Africa Republic	900 – 25,000	33 – 43	70 – 232
Chad			?
Comoros			?
Congo	2,120 – 12,200	69 – 242	11 – 44
Côte d'Ivoire	340	–	532 – (700)
Djibouti			?
Egypt	11,300	2,500 – 48,850	18,500 – 25,000*
Equatorial Guinea			?
Ethiopia	10	1	1
Gabon	1,500	–	5 – 8
Gambia			1
Ghana	30 – 1,400	120 – 204	300 – 360*
Guinea			5
Guinea Bissau			?
Kenya	12,200 – 32,140	610 – 3,000	625
Lesotho			10 – 29
Liberia	95 – 300	7 – 73	10 – 35
Libya			(700)
Madagascar	85,000	1,280 – 2,000	180-610 (17,400)
M 'awi	370 – 1,000	72 – 200	96 – 104
Mali			4
Mauritius	20	330	60 – 120*
Mauritania			?
Morocco			100
Mozambique	250	10	?
Namibia			?
Niger			18
Nigeria	300	61 – 2,000	20,500 (75,000)
Reunion			?
Rwanda	448 – 3,000	78 – 84	10 – 37 (180)
Sao Tome/Principe			?
Seychelles			?
Sénégal			14 (191)
Sierra Leone	162	2 – 7	3 – 7
Somalia			?
South Africa			300 – 600
Sudan	37	30 – 60	20 – 50
Swaziland	250	20	20 – 50
Tanzania + Zanzibar	8,000 – 10,000	1,000	200–500 (1,800)
Togo	514	8 – 60	300
Tunisia	7		168 – 186
Uganda	11,000	410	31 – 200
Western Sahara			?
Zaïre	122,070	4,000 – 4,200	125(700–5,000)
Zambia	1,708 – 3,160	350 – 460	300–1,000 (6,000)
Zimbabwe	5,000	12,500	800*
Total	269,650 – 335,367	23,092 – 77,968	43,400 – 52,594

N.B. Values in parentheses refer to unconfirmed statistics not included in totals.
*Values include production from practices such as acadjas, howash, dams, etc.

Dr. Smitherman applauded ICLARM's leadership in starting the process by calling the workshop. Other agencies and institutions like FAO, the International Development Research Centre of Canada (IDRC), The International Foundation for Science (IFS), the Oceanic Institute, the United States Agency for International Development (USAID) and other donors from countries such as the Federal Republic of Germany, France, Norway and the United Kingdom could perhaps be persuaded to pool some resources and join forces to support an international program on tilapia genetics research.

Dr. Pullin said that at present it is not clear which donor or donors might support international as opposed to bilateral research cooperation. However, the approach being proposed by ICLARM is similar to that followed for crop genetic improvement in the CGIAR system. As ICLARM is exploring an affiliation with the CGIAR system, the attitudes of donors to international fish genetics research may be clarified very soon.

Dr. Villwock commented that the EEC is a donor with strong interests in aquaculture and has plans for an Aquaculture Foundation. Future proposals can be sent to the EEC.

There followed a discussion on training needs and funding sources. It was agreed that training and research should be linked and that training needs in genetics research were great, particularly in Africa. The support of donors such as IDRC and IFS for individual researchers was felt to be particularly useful because their research activities help to build international capacity as well.

Mr. Chen Foo Yan stressed the value of in-service training of junior scientists in research - a good system for international cooperation.

Dr. Hulata said that Israel's Ministry of Agriculture's Center for International Agricultural Development and Cooperation (CINADCO) has considerable experience in training aquaculturists and will in future consider requests for putting on courses in third-world countries as well as in Israel.

Drs. Coche and Pullin mentioned that FAO and ICLARM have assembled data bases on aquaculture training opportunities from which information can be supplied to prospective trainees.

Recommendations

The following recommendations were agreed on by the workshop participants:

1. Donors supporting aquaculture research should recognize the current importance and enormous future potential of tilapia culture for nutrition and income improvement in third-world countries and should increase their funding for genetic research. It can play a major role in increasing production, as it has for other fish, crops and livestock.

2. It was recommended that a program of international research cooperation in tilapia genetics be established with strong leadership and coordination and sustained funding. It should involve international, regional and national institutions and agencies and, in addition to its research objectives, should strive to strengthen the genetic research capability of third-world country institutions, particularly in Africa and Asia, by training, workshops and staff exchanges.

3. It was recommended that the program should a) be interactive with a parallel effort to improve culture systems technology, particularly in Africa and Asia, b) include documentation of tilapia genetic resources (wild and cultured stocks), conservation measures and establishment of tilapia collections, c) commence at once (delays may mean the irreversible loss of important genetic resources through habitat despoilation and fish transfers) and d) focus on *Oreochromis niloticus* and *O. aureus*, with studies on wild stocks throughout their natural range and cultured stocks of known history (where these species cannot be used, - a number of other species merit further work for example, *O. spilurus, O. shiranus, O. urolepis hornorum, Tilapia rendalli, Sarotherodon melanotheron*, the red tilapias and others still to be screened for culture potential).

4. It was recommended that further identification aids, particularly field guides, be developed for the documentation of tilapia genetic resources. Collaboration between taxonomists, field biologists and international organizations such as FAO and ICLARM was recommended to produce these as soon as possible. Further work on the population genetics of wild and cultured tilapia stocks using electrophoretic, immunological morphometric and meristic

data analysis and the training of third-world-country biologists in these techniques were also recommended.

5. It was recommended that an international registry of tilapia strains be compiled and managed by an appropriate international organization. The registry must have excellent information and database management for numerical data; photographic material and information on collections of wild and farmed stocks. Close cooperation with museums and other institutions holding tilapia collections is essential. Information should be disseminated regularly to interested parties, for example by a newsletter.

6. It was recommended that immediate conservation measures be sought for protection of important wild stocks and their natural habitats in Africa. It was recognized that such protection cannot be afforded to all wild stocks, but it was recommended that undisturbed riverine and lacustrine populations (chosen to represent the two major species and important stocks of other species) should be identified and protected. Such protection requires a much more responsible attitude to fish transfers than in the past because tilapias stocked into natural waters or escapees from farms may interbreed with or outcompete native stocks. For all tilapia transfers into and within Africa an exchange of letters of no objection between the suppliers, recipients and all concerned government agencies and other interested parties, should be mandatory *prior* to shipment. Such letters should specify the origin and detailed history of the fish. This is particularly important when the proposed transfer may affect aquatic ecosystems in more than one country. Ideally an International Code of Practice as formulated by the International Council for Exploration of the Sea and the European Inland Fisheries Advisory Commission (Turner 1987) should be followed to ensure a thorough analysis of the possible consequences of transfers and the application of quarantine procedures. Details of all transfers should be communicated to the international registry and recorded.

7. It was recommended that tilapia collections be established, including: a) preserved specimens, b) live fish and c) cryopreserved sperm. These should be maintained in secure, competent, nonprofit institutions and should be replicated as an insurance against loss or damage. A code of practice should be drawn up for the collection and maintenance of live fish collections to avoid undesirable genetic effects such as founder effects, bottlenecks and inbreeding depression. Sperm banks should be established and managed following the codes of practice already established for crop germplasm and livestock sperm/embryo banks. It is particularly important to establish live tilapia collections in the tropics where they can be bred year-round and used in research programs in cooperation with farmers. Institutions having live fish and/or sperm collections must maintain accurate detailed records and make these available to the international registry. Material from collections must be accessible to the international scientific community for research to develop improved breeds.

8. It was recommended that breeding schemes pay particular attention to genotype x environment interaction, as tilapias are grown in a wide variety of culture systems - ponds, cages, raceways and tanks. In selective breeding, family selection or a combination of family and individual ('mass') selection was recommended. When testing introduced or new breeds in a new environment, it was felt essential to continue the evaluation program for two generations or more.

9. It was recommended that research methods be improved and standardized for all program activities. In particular, standardization of descriptive criteria and nomenclature for species and strains is essential and leadership for this should be provided from the international registry. Rigorous standards for the maintenance of collections and rigorous assay methods for comparative evaluation of performance with respect to commercial traits, especially growth, are required. A handbook of research methods, supplemented as further progress is made, would be an important step towards standardization.

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Appendix I

Genetic Improvement of Tilapias: Problems and Prospects*

Reprinted from:

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Abstract

Tilapias are cultured throughout the tropics and subtropics but little attention has been given to genetic improvement of cultured breeds. The largest tilapia culture industries are in Asia whereas nearly all tilapia genetic resources are in Africa. This paper discusses approaches to tilapia genetic improvement: documentation of genetic resources; evaluation of the culture performance and the use of promising material in breeding programs. Conservation of genetic resources, research methods and prospects for genetic improvement are discussed. The major emphasis is on the most popular cultured species, *Oreochromis niloticus*.

Introduction

Tilapias are cultured throughout the tropics and subtropics and the scope for growth of tilapia culture is vast (Pullin 1985). The most popular species is *Oreochromis niloticus* because of its good growth in freshwater. There is lesser but significant use of *O. aureus*, because of its cold tolerance and suitability for production of monosex male hybrid fry in intensive systems. Several other species are cultured where *O. niloticus* is not available or where they are preferred for various reasons, principally traditional and environmental. Red, orange and other colored tilapias, mostly hybrids, are also produced for a limited market. This paper

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considers the prospects and problems for genetic improvement of cultured tilapias and concentrates on *O. niloticus*.

The Feasibility of Genetic Improvement of Tilapias

Research for the genetic improvement of cultured fish has a short history compared to that for crops and domestic animals. There is now a broad consensus that applied genetics, particularly quantitative genetics, can have tremendous impact on aquaculture (e.g., Gjedrem 1985). However, most tilapia genetics research has been on hybridization and monosex male fry production (Wohlfarth and Hulata 1983). The few studies made on selective breeding and heritability of commercial traits are summarized in Table 1: note the possibilities of bottleneck and/or founder effects for some of the *O. niloticus* populations.

There are other problems with research methodology. For example, in comparative trials, different genotypes should be tagged and co-stocked in the same pond or cage and corrections made for differences in initial length or weight (Wohlfarth and Hulata 1983). Until such

Table 1. Summary of quantitative genetics research on growth performance traits in cultured tilapia (*Oreochromis* spp.); data for length and weight traits at various ages are pooled.

Location	Fish	Type of study; Results	Remarks
Auburn, USA	*O.n. niloticus*[1]	Heritability estimation by half-sib analysis: h^2 not significantly different from zero	Low variability (Tave and Smitherman 1980)
Georgia, USA	*O. aureus*[2]	Bidirectional mass selection: positive response, high lines 7-27% > low lines; $h^2 = 0.24 (\pm 0.07)$	Good response (Bondari et al. 1983)
Auburn, USA	*O.n. niloticus*[1]	$h^2 = -0.10$	(Teichert-Coddington and Smitherman, cited by Hulata et al. 1986)
Philippines	*O. niloticus*[3]	Bidirectional family selection: very slight response	Possibly low variability (Abella et al. 1986)
Israel	*O.n. niloticus* (Ghana strain)	Mass selection: no response	Probably low variability (Hulata et al. 1986)
Thailand	Red tilapia[4]	Mass selection: positive response selected line 10-30% > control; $h^2 = 0.17 - 0.19$	Good response (Jarimopas 1986)

[1] 50-100 fish (non-native; see text) transferred from Côte d'Ivoire to Brazil, 1971; 100-200 juveniles from 5-10 parents transferred to Auburn from Brazil, 1974; thereafter 150-200 randomly mating pairs maintained.

[2] (To be added).

[3] Experimental founder stock prepared by crossing introduced Israel, Singapore and Taiwanese 'strains'; all probably came via Israel, predominantly Ghana strain.

[4] An *O. niloticus*-*O. mossambicus* hybrid (see Pante et al., in press).

methods are well established, the evaluation of different tilapias and their use in selective breeding schemes will make little progress. Meanwhile, there is no reason to suppose that the potential for culture performance improvement through selective breeding forecast by Gjedrem (1985) for a "wide range of aquatic animals" should not include the tilapias. The short generation time for *O. niloticus* (about four months) and its capacity to breed year-round in the tropics mean that any genetic gains will be rapidly obtainable. However, there are major problems--limited information and availability of tilapia genetic resources.

The largest tilapia culture industries are in Asia; for example, the Philippines (Smith and Pullin 1984) whereas all important natural tilapia genetic resources are in Africa. Genetic improvement research should serve existing and emergent culture industries. Tilapia culture in Africa, with some exceptions, is probably not yet sufficiently developed to interface with such research. Tilapia culture in Asia, at least its more organized sectors, is sufficiently developed for this, but the problems of bringing together the required resources are immense. Good fish genetics research facilities are scarce throughout the tropics. Moreover, genetic resources are a global asset. If African tilapia genetic resources are to be used to improve global tilapia production, then African aquaculture research and development must receive commensurate support so that these can prosper. This will require much greater interregional and international cooperation.

Tilapia Genetic Resources in Africa

The natural distribution of tilapias has been reviewed by Philippart and Ruwet (1982) and Trewavas (1983). For *O. niloticus*, the natural distribution of subspecies, mostly clustered in central and east Africa, is summarized in Fig. 1. Numerous transfers, many undocumented, have been made between and within African nations and, more importantly, between river basins (Philippart and Ruwet 1982). Some recent transfers of *O. niloticus* and *O. aureus* have been made from western universities and Israel to Africa.

O. niloticus now extends beyond its native range in Africa. For example, *O. niloticus* is non-native to the south-flowing rivers west of the Volta in Ghana and Côte d'Ivoire. Its Soudanian form is native to only a few extreme northern, north-flowing streams in the Côte d'Ivoire (Daget and Iltis 1965). However, *O. niloticus* 'Bouaké' strain (a mixture of earlier introductions) is now widely cultured in Ivorian freshwaters. From farms close to the Bia River, it may have colonized the Bia and Tano Rivers which are shared with Ghana. If so, further tranfers to mix these fish with the Volta strain of *O. niloticus* could occur.

Obviously a balanced view is necessary with respect to tilapia transfers. They will continue to be thought acceptable where better fish can significantly improve established aquaculture to benefit needy people. Where risks to important genetic resources outweigh such benefits, transfers are best prevented. Conservation is vital for important native tilapia populations: ideally for all undisturbed riverine and lacustrine populations throughout Africa. Payne and Collinson (1983), describing such populations in Lake Manzallah, state "The existing widespread transport of stocks whose original provenance and genetic background are uncertain can lead to breakdown of local species differences and will certainly make the job of the selective fish breeder so much more difficult when the critical hurdle of true domestication is approached."

Tilapia Genetic Resources in Asia

Published information on *O. niloticus* intoductions to and transfers within Asia

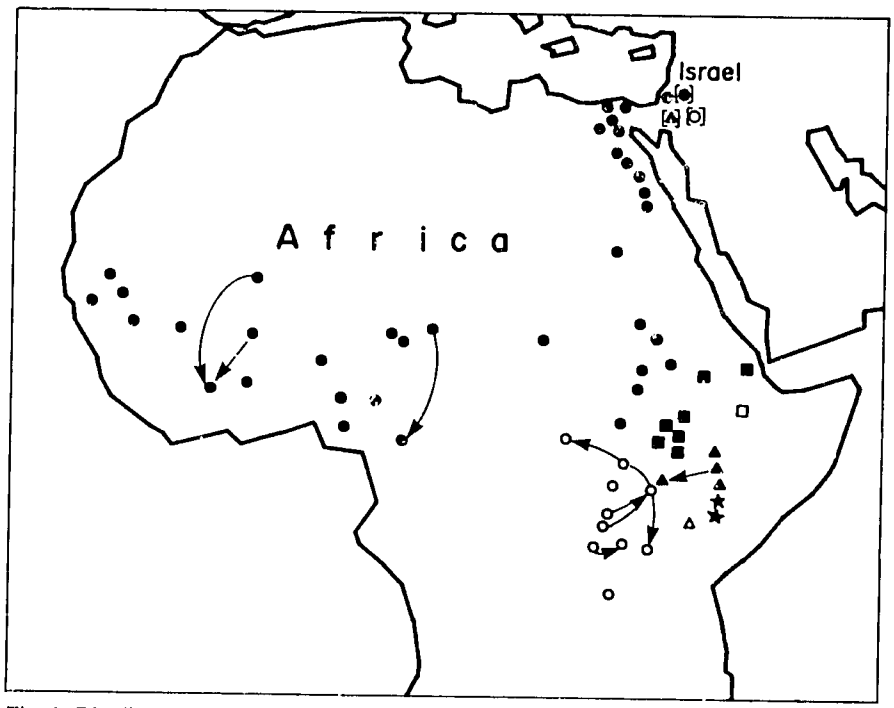

Fig. 1. Distribution of *Oreochromis niloticus* subspecies in Africa (modified after Trewavas 1983) and their transfers within Africa and to Israel for aquaculture and research purposes. Key: ● = *O.n. niloticus;* ○ = *O.n. eduardianus;* ■ = *O.n. cancellatus;* □ = *O.n. filoa;* ▲ = *O.n. vulcani;* △ = *O.n. baringoensis;* ★ = *O.n. sugutae.* Arrows indicate some transfers within Africa. Israel has received introductions bracketed [ ]: [●] *O.n. niloticus,* Ghana; [○] *O.n. eduardianus,* Uganda and [▲] *O.n. vulcani,* Kenya.

is summarized in Table 2 and Fig. 2. Many other unrecorded transfers have been made within Asia. However, to our knowledge, no direct introductions have been made other than those from: 1) the Nile River, Sudan, to Hubei Province, People's Republic of China, in 1978--two shipments of fish (27 and 34 fish, with 90% survival during transportation); despite the need to overwinter broodstock here, the fish bred in 1979 and now a tilapia hatchery industry produces 100 million fry/year in this province (He Yu-kang, pers. comm.); 2) from Cairo, Egypt to Japan: about 200 individuals were shipped and about 120 survived; the exact origin (farm or wild stock) is not known (T. Maruyama, pers. comm.). The Japanese stock seems to have maintained a high genetic variability: observed heterozygosity (H_o) = 0.091 (Basiao and Taniguchi 1984). Fifty fish were sent from Japan to Thailand in 1965 (Chotiyarnwong 1971). However, the number that survived to breed (the founder stock) in Thailand is unclear. This stock is called the Chitralada strain. The fish in the palace pond have been kept well-isolated from other tilapias. A sample of 20 Chitralada strain fish from the Asian Institute of Technology (AIT) examined in 1984 at 21 protein loci had H^o = 0.014 (ICLARM and the University of the Philippines, unpublished data), which indicates that a bottleneck has occurred at some stage. However, the Chitralada

Table 2. Introductions of *Oreochromis niloticus* to and subsequent transfers within Asia: summarized from Welcomme (1981) and Guerrero (1985). For additional information see Fig. 2.

Date	To	From	Date	To	From
1962	Japan	Egypt	1974	Bangladesh	Thailand
1965	Thailand	Japan	1978	China	Sudan
1969	Indonesia	Taiwan	Late 1970s	Sri Lanka	Israel
1972	Philippines	Israel[1]	1979	Philippines	Israel[2]
1972	Philippines	Israel	1979	Philippines	Singapore[3]
1972	Philippines	Thailand	1984	Philippines	Taiwan
1972	Hong Kong	Taiwan			

[1] Uganda strain — current status unclear.
[2] Ghana strain.
[3] Origin Israel, Ghana strain.

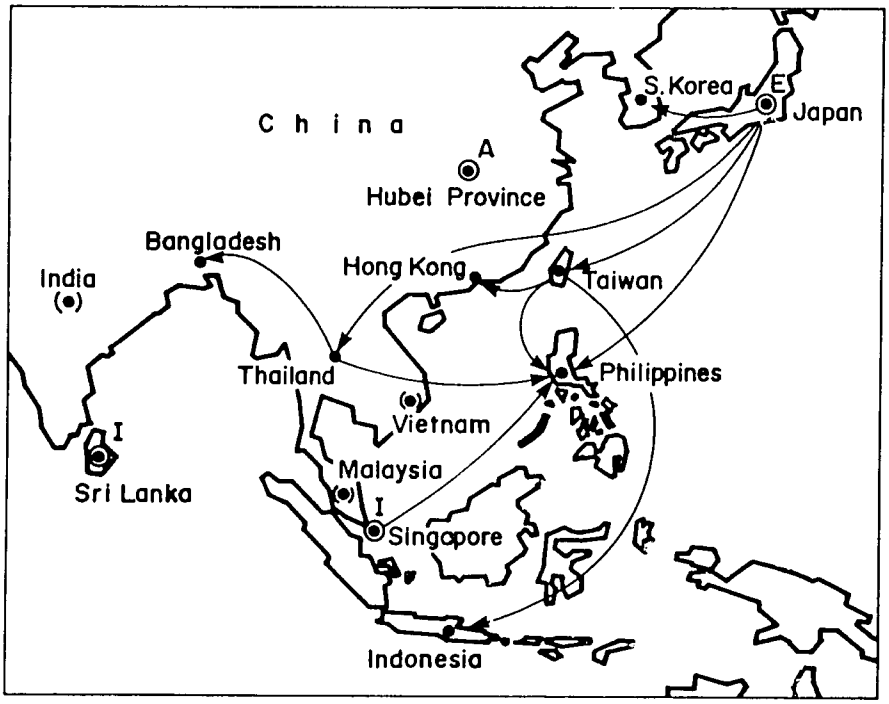

Fig. 2. Introductions of *Oreochromis niloticus niloticus* to Asia and some subsequent transfers between Asian countries based on Welcomme (1981), Guerrero (1985) and authors' unpublished observations. Entries bracketed ( ) indicate presence of stocks transferred from undocumented sources within Asia. ◉ = primary introductions to Asia from origins A (Sudan); E (Egypt); I (Israel, Ghana strain); ● = transfers within Asia. Many recent transfers within Asia are omitted for clarity and/or insufficient information (see also Table 1).

strain has performed very well in Thai aquaculture to date.

The other Asian *O. niloticus* populations have all come via Israel. Few details are published of the founder stocks but their impact has been tremendous; for example 50,000 t/year production in the Philippines (Smith and Pullin 1984). The relevant original introductions of *O. niloticus* from Africa to Israel were: 1) *O.n. eduardianus* from Kajansi Station, Uganda (origin Lake George), 120 fry in 1969 and a further sample in 1970 (Pruginin et al. 1975); 2) nine females and two males from the Volta, Ghana, in 1974 (Hulata et al. 1986).

The general conclusion is clear. The genetic diversity of cultured *O. niloticus* in Asia is probably low and a poor base from which to attempt selective breeding. Moreover, *O. mossambicus* is present in many Asian waters. Introgressive hybridization between such fish and *O. niloticus* affects culturists and researchers (Macaranas et al. 1986). However, based on our unpublished observations and on electrophoretic analysis of a sample of 20 fish from Pathum Thani Province (Macaranas et al. 1986), *O. niloticus* in central Thailand seem relatively unaffected. To sustain and hopefully improve Asian tilapia culture there is a strong case for new introductions from Africa. But which of the African populations are of most interest?

Moreau et al. (1986) recommend ϕ' (= $\log_{10} K + 2 \log_{10} L_\infty$; where K and L_∞ are parameters of the von Bertalanffy growth equation) for tilapia growth comparisons. For *O.n. niloticus* from many different waters (native and introduced populations) ϕ' ranged from 2.36 to 3.11. However, values from Lake Kainji (ϕ' = 3.11) and Lake Nasser (ϕ' = 3.07) fish were markedly higher than the remainder (ϕ' = 2.36 to 2.77). *O.n. eduardianus*, (Lake Albert) had a high value of ϕ' = 2.88 (Moreau et al. 1986). For the Lake George fish, Lowe-McConnell (1958), cited by Trewavas (1983), estimated that a 23-cm total length (TL) individual would grow 9 to 10 cm in a year and that the average TL at reaching sexual maturity was 28 cm, reached in the second year.

O.n. vulcani has been cultured at Dor, Israel in semi-intensive polyculture (Yashouv and Halevy 1972): its daily growth increments were 2.9 g (spring) and 3.4 g (summer). In Lake Turkana, Worthington and Ricardo (1936) and Lowe-McConnell (1958), cited by Trewavas (1983), estimated its maximum TL as 64 cm. However, the weight for length (condition) was the same as for Lake George fish. Stunted fish were recorded from Crater Lake C., Ferguson Spit and Loiengalani. *O.n. baringoensis* has a low maximum TL of 36 cm and matures at 18 cm (Ssentongo and Mann 1971), cited by Trewavas (1983).

There is little additional information and much of that cited here may be of limited use as an indicator of culture potential because of the tremendous plasticity of tilapias with respect to growth and reproduction in different environments (Lowe-McConnell 1982). However, the possession of a high ϕ' value is probably a good indicator of high growth potential in a suitable culture environment (see Pauly et al., in press). It is clear that much more work is needed to investigate the variability of different *O. niloticus* stocks for commercial traits. For example, those at the extremes of the geographical range (such as Egypt) and those in adverse environments (such as higher elevations) may be of particular interest for subtropical culture.

Future Research: Documentation and Conservation of Tilapia Genetic Resources; Comparative Evaluation and Breeding Programs

It is clear that tilapia genetic resources are poorly documented. A major effort is needed to survey these and to enact conservation measures for important wild populations and their habitats. Similar recommendations for

other fish have been widely published (FAO/UNEP 1981; Ryman 1981; Meffe 1986). Their execution faces enormous financial, logistical and political problems. However, something must be done. It should be possible to assess the status of at least some of the more important populations and to conserve some material in the wild and in culture collections.

This raises the possibility of gene banks. Unlike crops for which germplasm is easily stored--for example the International Rice Research Institute germplasm banks (duplicated between the Philippines and the USA) comprised 61,000 Asian cultivars, 2,575 African rices, 1,100 wild rices and 680 testers in 1982 (Chang 1983)--and farm livestock for which cryogenic storage of semen and embryos is widely practiced (FAO/UNEP 1984; Smith 1984), the technology available for fish gene banks is restricted to the maintenance of live fish collections and cryopreservation of spermatozoa. Live fish collections are expensive to maintain and require very careful management. Replication at different locations is essential. Sperm banks, recommended by Harvey (1987) are potentially a useful means of conserving and distributing material, but monosex haploid gene banks have obvious limitations. They also require rigorous quality control standards and database management. Future documentation and conservation work on tilapia genetic resources may, therefore, involve three approaches: conservation of natural populations, live fish collections and sperm banks.

Further research on the estimation of genetic parameters, comparative evaluation of different tilapias for culture performance and breeding schemes to produce genetically improved breeds should be undertaken in close cooperation with farmers. Just as for crops and livestock, there are elements here of on-station and on-farm research which are highly interactive. The approaches used successfully in salmonid culture, particularly in Norway (Gjedrem 1985), could be repeated for tilapias, provided that the required support and climate of international cooperation are forthcoming.

Given the growing importance of Asian tilapia culture and renewed interest in African aquaculture we are convinced that a major program to document, conserve, evaluate and utilize tilapia genetic resources is urgently needed and we are optimistic that it will attract the necessary sustained support.

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Appendix II

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Genetic Considerations on Acquisition and Maintenance of Reference Populations of Tilapia[1]

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Acquisition and maintenance of reference populations of tilapia would be an important development in aquaculture, because they could be used to supply aquaculturists with broodfish of good genetic quality. A number of reference populations should be established, because there are several important species of tilapia, and because there are populations or subspecies within each species. Each reference population should be managed so that it will not be contaminated with genetic material from another population.

The most important genetic goal in the acquisition and maintenance of a standard reference population is conservation of the gene pool to prevent genetic drift and to prevent detrimental levels of inbreeding, so that gene and genotypic frequencies will not change significantly over time. This may be accomplished by managing the population's effective breeding number (N_e), which is a function of the number of males and females that produce viable offspring, the sex ratio of the fish that produce offspring, the system of mating and the variance of family size. Most tilapia culturists use random mating, and when this is used, N_e is:

$$N_e = \frac{4\,(♀)\,(♂)}{(♀) + (♂)}$$

where ♀ and ♂ are the number of females and males that produce viable offspring.

Knowledge of a population's N_e is crucial, because it is inversely related to inbreeding and to genetic drift. Restrictions in N_e can create irreversible damage to a population's genetic and biological potential.

Conserving a stock's biological potential involves managing its N_e so that it does not go below a pre-determined number. Minimum desired N_e is determined by the maximum desirable level of inbreeding, frequency of the rarest alleles to be saved and the probability of saving the alleles that is desired, and number of generations involved (broodstock replacement interval). If N_e is allowed to decline below the minimum desired number for even a single generation, a genetic bottleneck can occur, which can permanently damage the genetic quality of a population.

To properly manage a standard reference population's gene pool, the following genetic goals should be incorporated: inbreeding should not exceed 5%; alleles whose frequency = 0.01 should be saved and the probability of saving the alleles should be 99% (P = 0.01). Finally, long-term planning must be incorporated into the management program, and 25 to 50 generations (usually 25-50 years) is appropriate. To achieve these goals, N_e should be 390-500 per generation.

Founder stocks gathered from the wild should have broad genetic bases and minimal inbreeding. Most hatchery stocks have some inbreeding and have reduced heterozygosity. Wild populations should be studied prior to acquisition to determine sample areas and to provide base-line data on genetic variance and gene frequencies, which will be used as standards during acquisition and management of the population. Depending on goals, the reference population can be created from a single wild population or from several wild populations.

Care should be taken to ensure that the gene pool is adequately sampled. The N_e for the foundation generation will be determined when they reproduce, so sample sizes should be adequate to compensate for mortality and lack of spawning success.

In order to manage a reference population's N_e, reproduction must be stringently controlled. Traditionally, tilapia are spawned in ponds, and fish are allowed to choose their own mates. Knowledge of and management of N_e is impossible with this type of reproduction.

Fish should be paired in spawning nets or tanks. A 1:1 sex ratio maximizes N_e in a closed population. Pairing must be random; intentional or unintentional selection of broodfish must be prevented. This mating scheme will allow calculation of N_e. To maximize genetic variance, a fish should not be allowed to spawn more than once, unless all of its offspring die.

Each family should be raised in an individual net or tank for 20-30 days. Fry can then be transferred to ponds or tanks. Before stocking, family size should be equalized, because unequal family size lowers N_e.

When the fish become sexually mature, a random sample should be taken to be used as replacement for the previous generation. The sample should be larger than the desired N_e, because some fish will die, some will not spawn, and some fish must be killed for electrophoretic analysis to determine the effects of genetic drift. If this reveals that there were drastic changes in gene frequencies and that more alleles were lost than expected (based on N_e), the fish should be discarded and the parents should be mated again.

Requests to establish replicate reference populations must be received well in advance, so that production of the new generation for the reference population and production of fish for other hatcheries will be coordinated. Each request should be filled by spawning 195-250 pairs in nets or tanks, which is an N_e of 390-500. Total number of requests should be known before the spawning season to determine how many matings will be needed to fill the requests. Each request should be filled by shipping an equal number (minimum of 4) from each spawn. By including at least 4 fish per spawn, sample size will be at least 780-1,000 fish, which should be adequate to compensate for mortality and lack of spawning success.

[1] For a more detailed treatment of this topic, see: Tave, D. 1986. Genetics for fish hatchery managers. AVI Publishing Co, Westport, Connecticut; and Smitherman, R.O. and D. Tave. 1987. Maintenance of genetic quality in cultured tilapia. Asian Fisheries Science 1(1): 75-82.

Appendix III

Identification of Tilapia Populations Used for Fish Culture*

Introduction: General Considerations for Identifying Tilapias

There are three main groups of tilapias:

- Substrate brooders, guarders, with few (6-12) gill rakers on the lower limb of the anterior gill arch; often macrophyte feeders, with coarse teeth in the jaws and on the lower pharyngeal bone . . . genus *Tilapia*.
- Biparental, male or female mouth brooders, with 12 to 27 lower gill rakers; jaws and pharyngeal bones with fine teeth . . . genus *Sarotherodon*.
- Maternal mouth brooders, arena spawners; with 15 to 27 lower gill rakers; jaw and pharyngeal teeth ranging from fairly coarse to fine . . . genus *Oreochromis*.

In the key given below it will be noted that behavioral characteristics and colors of living fish, especially of breeding males, are important for identifying some species. Tilapias greatly resemble one another morphologically and many hybridize readily when introduced to new areas, which complicates identification. Coloration may vary according to social behavior, feeding and environmental factors (Falter 1987).

This guide is useful for determining the specific status of populations, rather than of individual fishes. It is necessary to look at electrophoretic differences and data from other biochemical tests to characterize some fish. Such techniques will be covered in a technical manual to be prepared by ICLARM.

The natural distribution of cultured tilapias is summarized in Figs. 1-3. However, fish transfers for culture and stocking purposes have changed this picture greatly.

What To Observe and Measure

Fig. 4A shows the most important diagnostic measurements. All measurements are in mm.

Standard length (SL): the total length from tip of snout to end of body, i.e., to base of caudal fin (where the fin rays reach the hypurals).

Total length (TL): used in fishery statistics but rarely in taxonomy: from tip of lower jaw to hind end of caudal fin.

Body depth (BD): the greatest depth, excluding fins; this varies greatly in fish from different waters.

Head length (hl): the longest measurement, from anterior edge of the upper lip to the most posterior part of the bony opercular edge (measured with caliper points on both sites).

Lower jaw (lj): length from the tip of the mandibular symphysis to the posterior edge of the lower jaw (find end of lower jaw hidden in flesh using thumbnail).

Caudal peduncle length (cpl): horizontal from end of the base of the dorsal fin to base of the caudal.

Caudal peduncle depth (cpd): the least depth of the caudal peduncle.

Gill raker number: the number of gill rakers on the anterior arch (Fig. 4B); unless stated otherwise these are the numbers on the lower part of the first gill arch (lower gill rakers), which

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*A field guide compiled by R.H. Lowe-McConnell, based on the monograph by E. Trewavas (1983) which should be consulted for further details.

are much easier to count than those on the upper half. However, where to stop counting, i.e., the raker at the angle, is not so easily determined in tilapias as in some other fishes and there may occasionally be two or no rakers, instead of one, at the hinge. The position of the gill arches can be seen in Fig. 4C.

Lateral line scales: in tilapias, as in other cichlids, the lateral line is divided into two parts; scales in the lateral-line series are counted first along the upper lateral line (ull), then along the

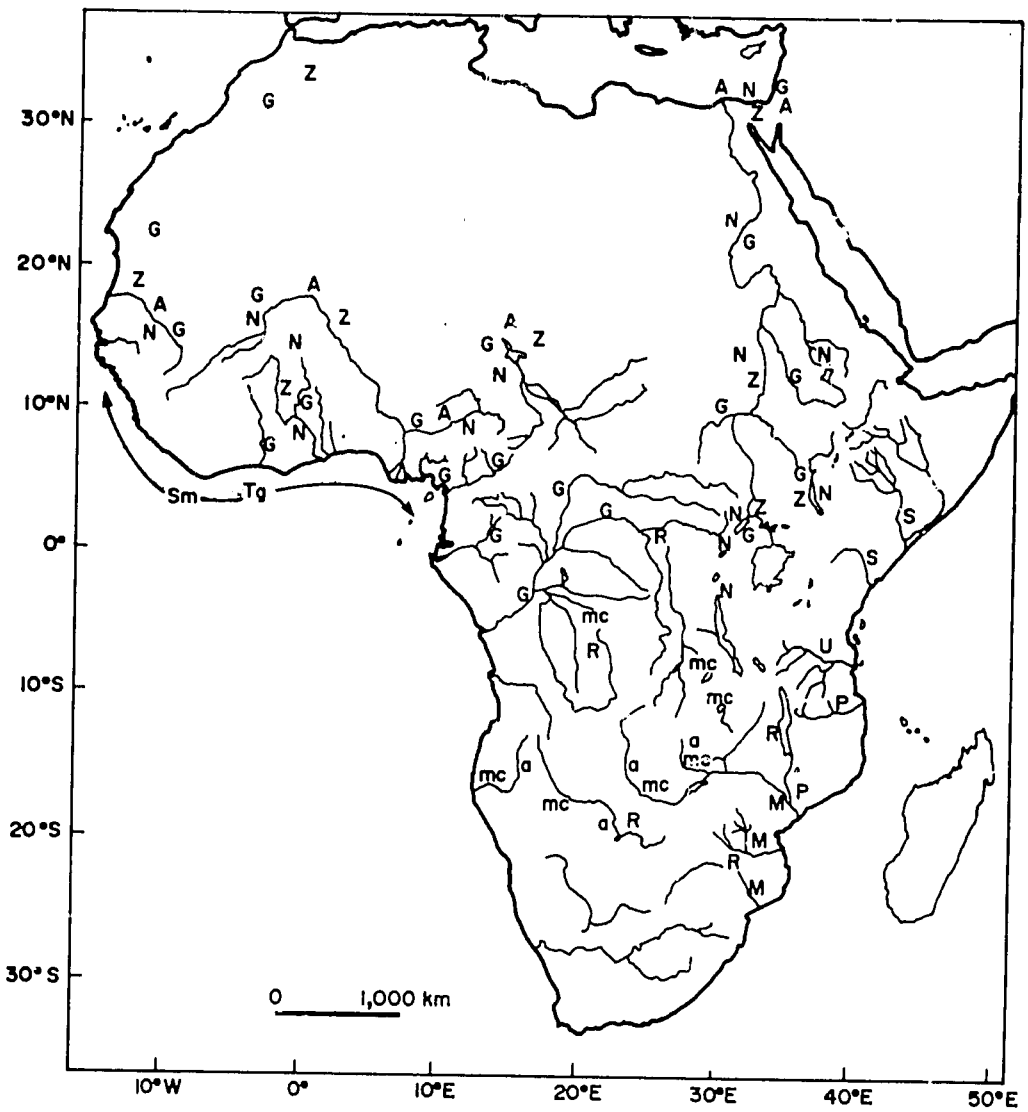

Fig. 1. The natural distributions of tilapias used in aquaculture. The species *Oreochromis niloticus* (N), *O. aureus* (A), *Sarotherodon galilaeus* (G) and *Tilapia zillii* (Z) all have a soudanian distribution from West Africa to the Nile valley. *O. aureus*, sympatric with *O. niloticus* in the Nile delta, extends to the Jordan Valley. *T. rendalli* (R) is a southern form, widely distributed in Central Africa, as is *O. macrochir* (mc) and *O. andersonii* (a). *S. melanotheron* (Sm) and *T. guineensis* (Tg) inhabit West African coastal lagoons. Distributions of east-flowing river species (including *O. spilurus* (S), *O. urolepis* (U), *O. placidus* (P) and *O. mossambicus* (M)) are shown in Fig. 3. Data from Trewavas (1983).

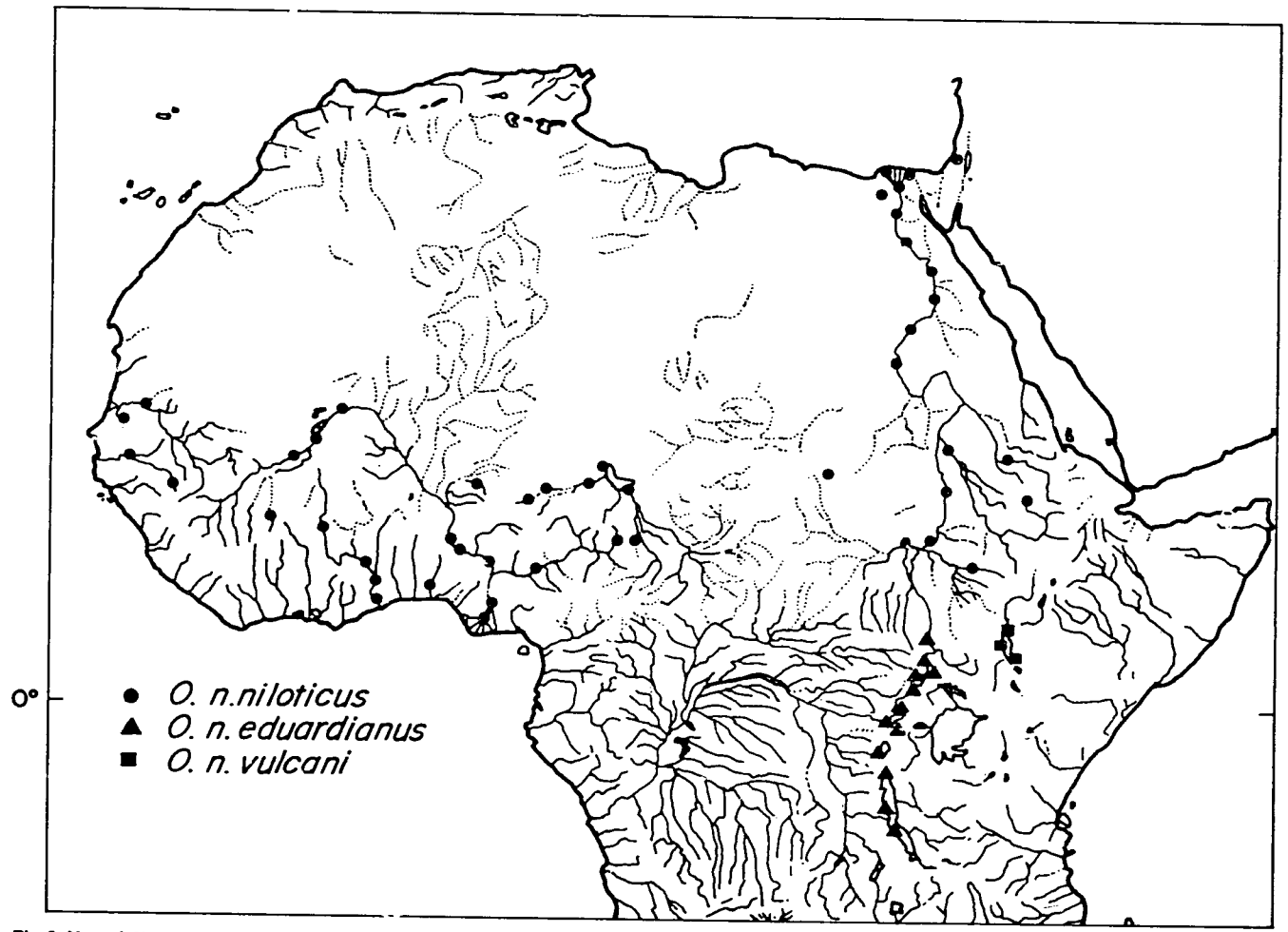

Fig. 2. Natural distribution of the subspecies of *Oreochromis niloticus* used in aquaculture. After Trewavas (1983), who gives details of the distribution of other subspecies.

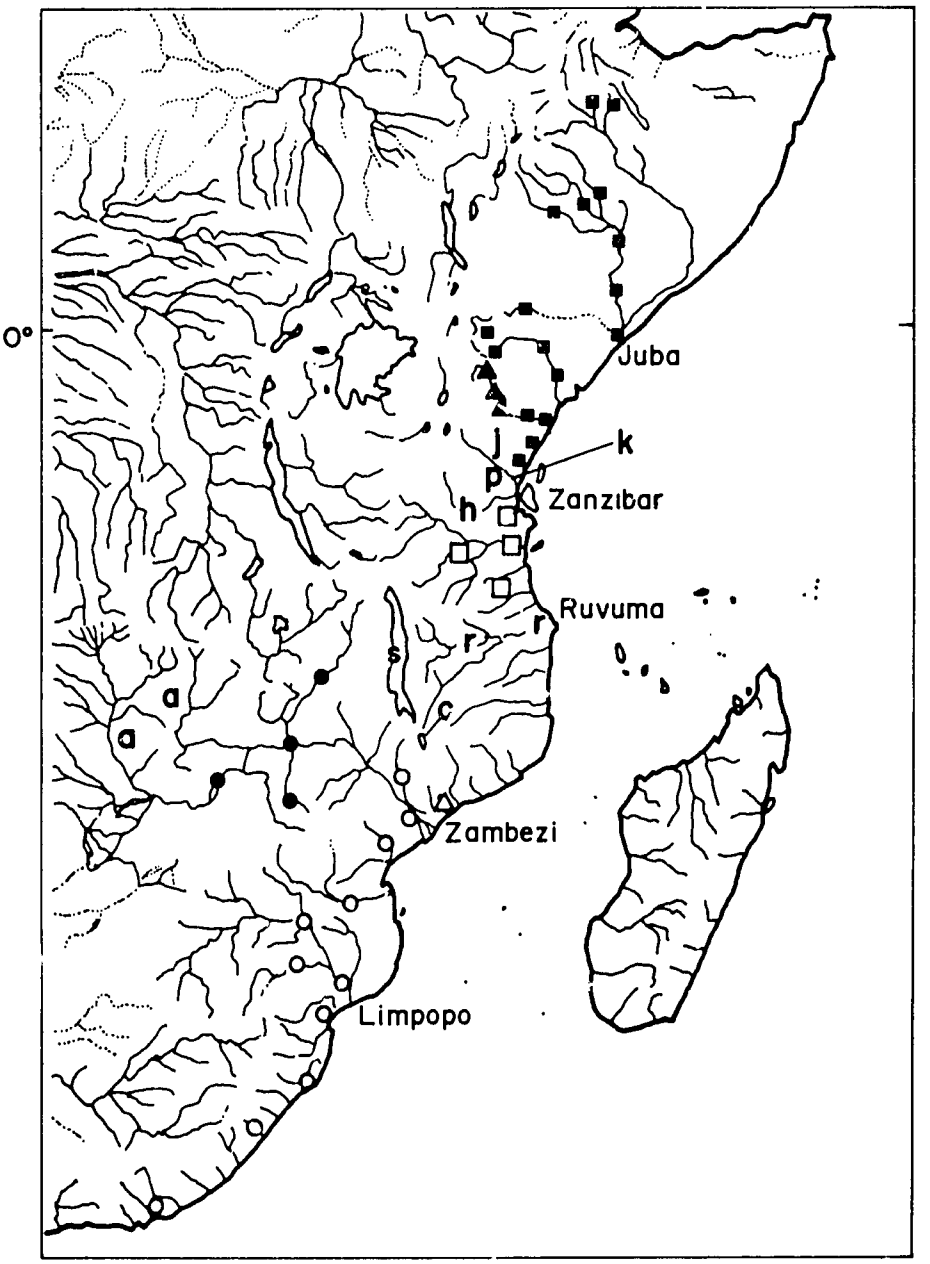

Fig. 3 . The natural distributions of *Oreochromis* tilapias in river systems of eastern Africa. Most species in lower reaches live in freshwater but can withstand brackish- or saltwater.

Somalia and Kenya: *O. spilurus* (▪) (*O.s. niger* in the Upper Athi); Tanzania: Lower Pangani *O. korogwe* (k) with *O. pangani* (p) upriver and *O. jipe* (j) in Lake Jipe; *O. urolepis* (▫), (*O.u. hornorum* (h) in the Wami and Zanzibar); *O. placidus ruvumae* (r) in Ruvuma; Zambezi system: Lower Zambezi, *O. placidus* (△), *O. mossambicus* (○) (also found in coastal rivers of southern Africa), replaced by *O. mortimeri* (●) Middle Zambezi; *O. andersonii* (a) Upper Zambezi and Kafue; *O.s. chilwae* (c) in Lake Chilwa; *O. shiranus* in Lake Malawi (s). Data from Trewavas (1983).

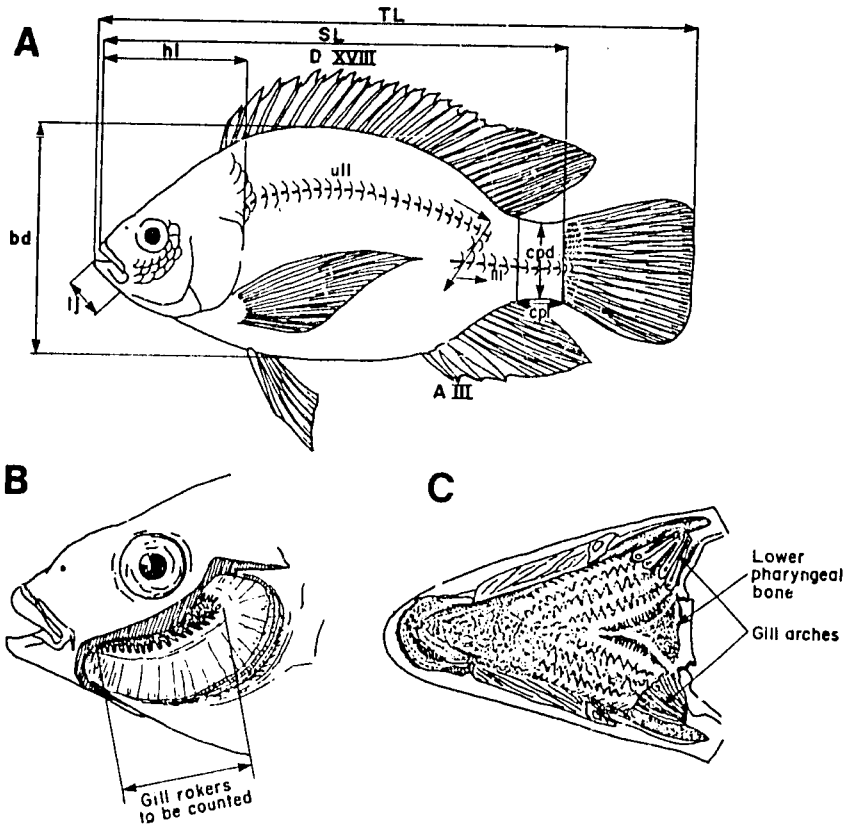

Fig. 4. A. Tilapia to show measurements used in identification of species. A = anal spines (here there are III); bd = body depth; cp = caudal peduncle length; D = dorsal fin spines (here there are XVIII); hl = head length; lj = lower jaw length; lll = lower lateral line; ull = upper lateral line. B. *Oreochromis* head with gill cover removed exposing gill rakers on anterior gill arch (18 on lower, 4 on upper). C. *Tilapia* head cut through mouth and pharynx to show lower jaw, position of gill arches and lower pharyngeal bone.

lower lateral line (lll) starting with the scale next behind the oblique row downwards and forwards of the last upper lateral-line scale (see Fig. 4A), i.e., do not count scales in the overlapping part.

Fin ray counts: dorsal (D) and anal (A) fin ray counts are useful diagnostic characters (*spines* are generally denoted by Roman numerals, *soft rays* by Arabic ones). The last dorsal or anal ray is counted if it is distinct to the base and if the penultimate compares well in size with the one before it (it usually has no endoskeletal support).

Lower pharyngeal bone: width (w) is greatest width from right to left (Fig. 5B); the length of the bone (l) and length of its dentiferous area (da) are measured in the median sagittal line. The position of this bone on the floor of the pharynx is shown in Fig. 4C. The best way to extract this bone without damaging the specimen is to lift the gill cover, continue forward the slit between the fourth gill arch and the blade of the bone with scissors, then cut the membrane along the side of the bone and the muscles joining its hind corner to the shoulder girdle; do the same on the other side, taking care not to cut the anterior blade; cut the bone away from the esophagus and from tissues beneath it; remove the bone, clean it of soft tissue and let it dry. After examination, the bone should be replaced in the fish if the specimen is to be kept.

Nest: the pit excavated for mating and guarded by the male is often of diagnostic shape in the maternal mouth-brooding tilapias.

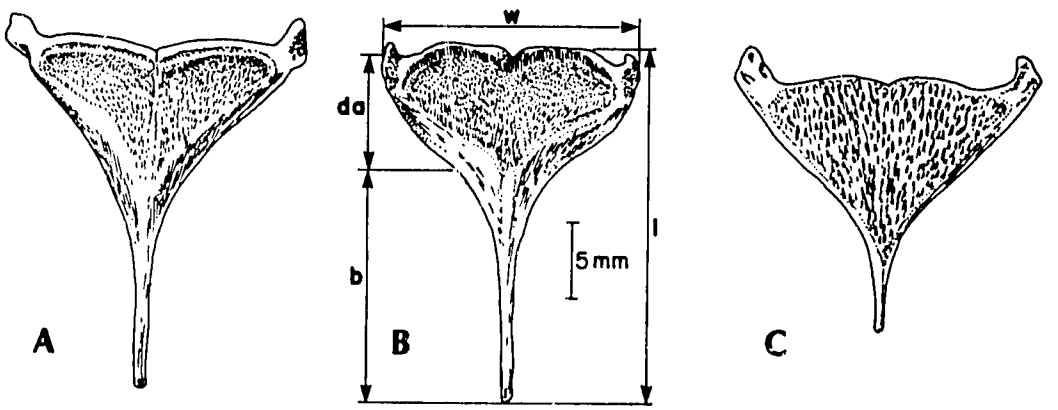

Fig. 5. Lower pharyngeal bones of A. *Oreochromis niloticus;* B. *Sarotherodon galilaeus* and C. *Tilapia rendalli:* da, dentiferous area; b, blade; l, length; w, width.

Other Important Characteristics

Most tilapiine species for culture are maternal mouth brooders: the *Oreochromis* Günther group. There are five subgenera among the maternal mouth brooders. Most species used in aquaculture belong to the *O. (Oreochromis)* subgenus (in which the mature male lacks a genital tassel). The general appearances of species most useful in culture are shown in Figs. 6-8, and their meristic characters are summarized below.

The *OREOCHROMIS* Group

The characteristics of *O. Oreochromis* include:

- Gill rakers (on lower part of anterior arch) 13-27.
- Anal spines III-VI.
- Marked color differences between the sexes when in breeding condition (sexual dichromatism).
- Marked shape differences between the sexes in most species (sexual dimorphism) expressed in mature males by longer dorsal, anal and pelvic fin rays and in enlarged jaws in which the notched teeth become replaced by unicuspids.
- Males lack a genital tassel; the male genital papilla is not produced into tubercles and filaments.
- Nest not provided with a central platform.
- Widespread in Africa and the Levant, but absent from West African rivers from the Corubel (Guinée-Bissau), Sierra Leone, Liberia to the rivers of Côte d'Ivoire and Ghana (west of the Volta) entering the Gulf of Guinée. Common in the upper parts of the Volta and Niger, from which they penetrate the lower parts of these rivers. Absent from the Central Basin of the Zaïre and from the western rivers of Cameroun. However, international transfers for aquaculture are constantly changing these natural distribution patterns.

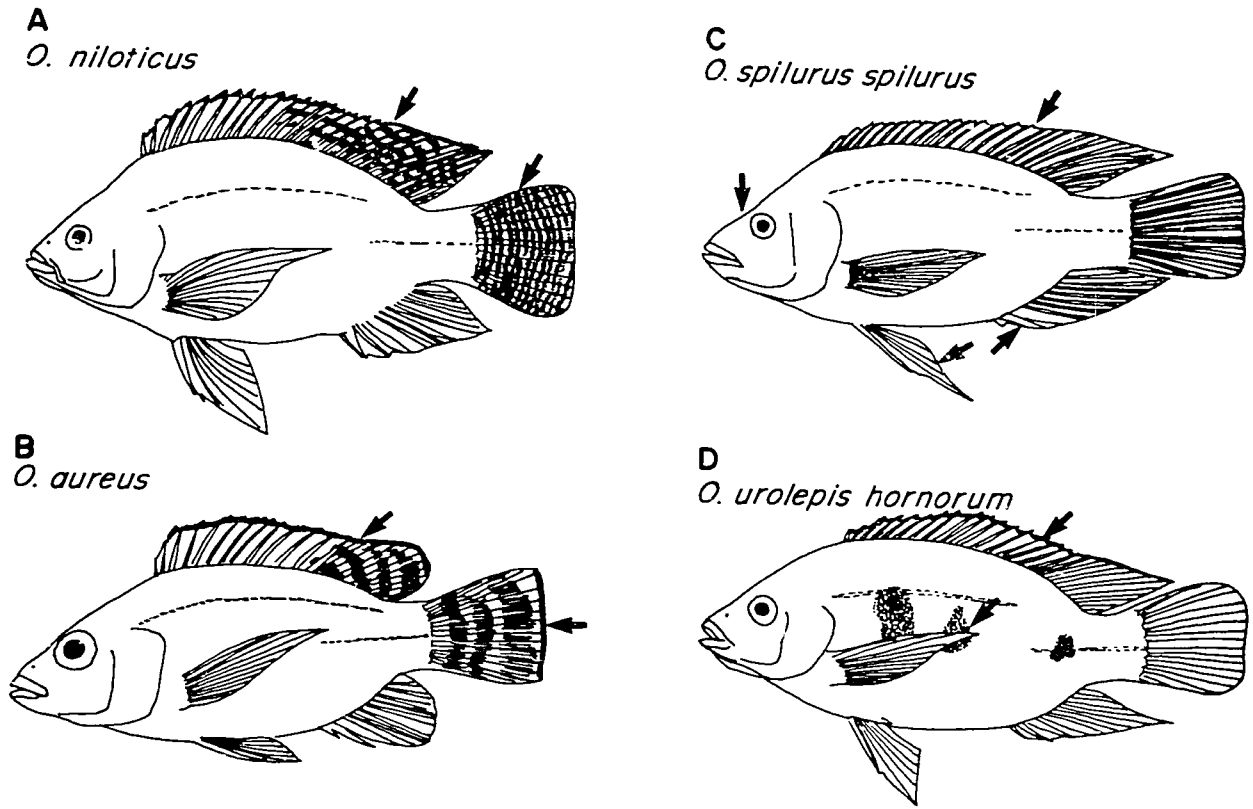

Fig. 6. *Oreochromis* species. Broad arrows indicate major distinguishing characters. A. *O. niloticus*–the caudal has regular verticular stripes and the dorsal margin is grey or black (outline drawing from Boulenger 1915, fig. 163). B. *O. aureus*–the dorsal and caudal of the male have red margins (outline drawing from Trewavas 1983, fig. 66). C. *O.s. spilurus*–the dorsal fin has orange lappets; the lower fins are blue; breeding males are often blue with black fins and have enlarged jaws (outline drawing from Trewavas 1983, fig. 79). D. *O. urolepis hornorum*–2 to 4 mid-lateral blotches; breeding males have narrow red margins to dorsal and black body (outline drawing from Trewavas 1983, fig. 95).

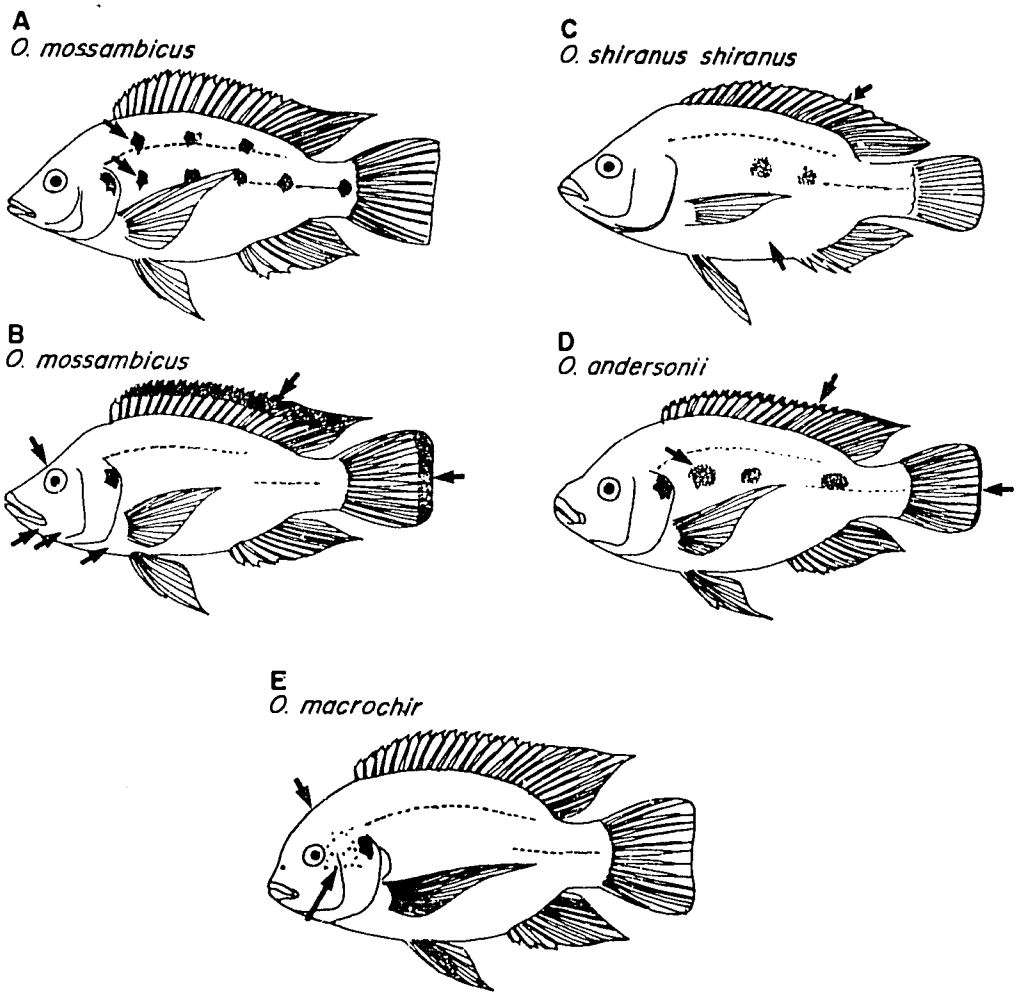

Fig. 7. *Oreochromis* species. Broad arrows indicate major distinguishing characters. A. *O. mossambicus* female, with lateral spots. B. *O. mossambicus* male, overall coloration black; white lower parts of the head and red margins of caudal and dorsal; note also concave upper profile and enlarged jaw in mature male (A and B) outline drawings from Boulenger 1915, figs. 103, 101). C. *O. shiranus shiranus*–head with concave upper profile, body typically olive-green, ventrally yellowish; orange lappets to dorsal (outline drawing from Trewavas 1983, fig. 113). D. *O. andersonii*–2 to 4 mid-lateral spots; red edges to dorsal and caudal (outline drawing from Boulenger 1915, fig. 130). E. *O. macrochir*–genital tassel develops in mature male (Nyasalapia group); dorsal profile of head very convex; head with red flecks, in male head becomes dark green and irridescent (outline drawing from Boulenger 1915, fig. 105).

Nine species of this subgenus are commonly used in aquaculture, some with subspecies:

- *Oreochromis niloticus* (Linnaeus); three of the subspecies have been cultured
  - *O.n. niloticus* (Linnaeus)
  - *O.n. eduardianus* (Boulenger)
  - *O.n. vulcani* (Trewavas)
- *Oreochromis aureus* (Steindachner)
- *Oreochromis spilurus;* two of the five subspecies have been cultured:
  - *O.s. spilurus* (Günther)
  - *O.s. niger* (Günther)
- *Oreochromis urolepis* (Norman), of which *O.u. hornorum* (Trewavas) is somewhat doubtfully distinguished as a subspecies.

- *Oreochromis mossambicus* (Peters).
- *Oreochromis mortimeri* (Trewavas), perhaps only subspecifically distinct from *O. mossambicus*.
- *Oreochromis shiranus shiranus* (Boulenger)
- *Oreochromis shiranus chilwae* (Trewavas)
- *Oreochromis andersonii* (Castelnau)
- *Oreochromis jipe* (Lowe-McConnell)

The subgenus *Nyasalapia*, also used in aquaculture, is characterized by:

- Presence of a genital tassel in mature males.
- Jaws not greatly enlarged in mature fishes.
- Anal spines III.
- Lower gill rakers 17-26.
- Sexual dimorphism not marked in lacustrine species.
- Sexual dichromatism marked and breeding habits as in *O. (Oreochromis)* but nest, where known, with central raised platform.
- Of the fifteen species from Central Africa and in western rivers from the Cunene to the lower Zaïre (many endemic to lakes, e.g., the Lake Malawi species flock), only one species, *O. macrochir* (Boulenger), has been widely used in fish culture, mainly in Central Africa.

Key to the Maternal Mouth-Brooding *(Oreochromine)* Tilapias Most Commonly Used in Fish Culture

Where certain meristic characters have more than one number listed, the bracketed figures are less common.

1a. Genital papilla of breeding male not tassellated (subgenus *OREOCHROMIS*) . . . 2.

1b. Genital papilla of mature male tassellated with prolonged tubercles and filaments (subgenus *NYASALAPIA*) . . . 5.

2a. Jaws of mature male not greatly enlarged (length of lower jaw 29-37% of head length) . . . 3.

2b. Jaws of mature male greatly enlarged (lower jaw reaching 38-50% of head length) . . . 4.

3a. *O. niloticus* (Fig. 6A). Caudal fin with regular vertical black stripes throughout its depth; margin of dorsal fin grey or black. Freshwater, except Nile delta; of wide natural distribution; three subspecies have been used in fish culture (Fig. 2):

(i) *O.n. niloticus*, widely distributed from West Africa to the Nile and Yarkon Rivers; Lake Chad basin and rivers Niger, Benoue, Volta, Gambia and Sénégal. Doubtfully native in the Jordan Valley but now perhaps stocked there artificially.

(ii) *O.n. eduardianus*, from Lakes Edward and George basins; Lake Albert; Lake Kivu; Ruzizi River and Lake Tanganyika; stocked in Lakes Victoria and Kyoga.

(iii) *O.n. vulcani*, from Lake Turkana (Rudolf) and crater lakes on Central Island; stream entering Lake Turkana; (probably introduced into Lake Victoria).

3b. *O. aureus*. Distinguished from *niloticus* mainly on live coloration; caudal with less regular markings; dorsal and caudal fin in male with red margins. Freshwater (except Nile Delta); Jordan Valley, Nile Delta; Chad; Niger; Sénégal; (see Fig. 6B).

4a. *O. spilurus*. Lower jaw of mature males greatly enlarged. Body color yellow-buff with orange lappets and blue lower fins; breeding male often blue with black fins.

Occurs naturally in freshwater to saltwater; coastal rivers of Kenya and Somalia; anal spines III (IV); (see Fig. 6C).

Note that there are two cultured subspecies (*O.s. spilurus* and *O.s. niger*); *O. spilurus niger* has body color as *O.s. spilurus* but with higher meristic numbers and is distinguished by anal spines IV-VI; formerly found in the upper reaches of the Athi River Kenya, but probably now mixed/hybridized with *O.s. spilurus*, except possibly in the Tsavo.

4b. *O. urolepis hornorum* (the 'Zanzibar tilapia' used in early hybridization experiments). Color, female and nonbreeding male silvery or steel-grey with 2-4 midlateral blotches; breeding male black with narrow red margin to dorsal fin; upper half of caudal with irregular vertical stripes or reticulations. Occurs in freshwater to brackishwater, Wami system (Tanzania) and Zanzibar (possibly introduced in 1918). Barely distinguishable from *O.u. urolepis* found in other Tanzanian river systems (including Rufigi and Great Ruaha, but not in the delta), by failure to develop a dense scaly covering to caudal fin and possibly by pigmentation of breeding male. The enlarged lower jaw of the male helps to distinguish this from *niloticus;* (see Fig. 6D).

4c. *O. mossambicus*. Breeding male black with white lower parts of head and red margins of dorsal and caudal fins. Freshwater to seawater; Lower Zambezi, Limpopo and eastern rivers southward. Lower jaw 32.0-45.5% head length, becomes greatly enlarged in mature males (see Figs. 7A and B).

Note: *O. mortimeri* (Trewavas), which occurs upriver in the Middle Zambezi and its tributaries including the Luangwa, the Hunyani and Lake Kariba, is possibly only subspecifically distinct from *mossambicus*, based on relatively 'shorter' caudal peduncle (8.8-12.4 compared with 10.0-13.7 in *mossambicus*), and color of mature males (predominantly irridescent blue-green to bronze, with irridescent spots on dorsal and caudal fins, in contrast to the deep black body with contrasting white throat of male *mossambicus;* in both species the margins of dorsal and caudal fins are red).

4d. *O. shiranus shiranus*. Olive green, yellow ventrally; males darker to black, with orange lappets. Freshwater, Lake Malawi and Upper Shire river. Anal spines (III) IV (V). See Fig. 7C.

O. shiranus chilwae is a distinct subspecies; body color. Silvery, darker above, males darker to nearly black, with red lappets. Occurs in alkaline water, Lake Chilwa only, but spread for aquaculture. Anal spines (III) IV.

4e. *O. andersonii*. Nonbreeding fish and female with 2-4 midlateral dark blotches; dorsal and caudal red-edged or caudal and anal with red more extensive; breeding male with red margins broader and brighter and generally dark; irridescent purplish-brown head, back and flanks masking the lateral blotches; no stripes on caudal fin. Nest, a simple circular depression. A large-growing species; jaw enlargement in large males only. Freshwater, Upper Zambezi, Kafue, Okavango, Cunene. See Fig. 7D.

4f. *O. jipe*. Scales with dark centers and golden-yellow edges, caudal fin with dark vertical stripes. Lateral-line scale number high, 33-36. Anal spines III or IV (V). Endemic to Lake Jipe in the Pangani River system, Tanzania. Not illustrated.

5. *O. macrochir*. Mature male with white genital papilla. Head green with red flecks, dorsal profile of head very convex. Breeding males very dark green, irridescent with bright red margin to dorsal and caudal. Lower jaw 27.0-36.0% head length, that of male not enlarged. Used extensively for stocking dams and ponds in Central Africa. See Fig. 7E.

Two subspecies are recognized:

(i) *O.m. macrochir* (Boulenger) found in the Upper Zambezi, Okavango and Ngami region, Cunene basin, Kafue River, Chambezi River and Bangweulu region; distinguished by toothed area of lower pharyngeal bone with broadly rounded lobes and mating territory having a central volcano-shaped mound with a flat or slightly concave top.

(ii) *O.m. mweruensis* (Trewavas), found in Lake Mweru and lower Luapula and Lufira Rivers; with toothed area of lower pharyngeal bone with more acute lobes and mating territory with 'star-shaped nest', a low mound with 6-12 grooves and crests radiating from the small central concave area.

The *SAROTHERODON* Group

Characteristics of *Sarotherodon* Rüppell include:

- Gill rakers (lower part anterior arch) 12-27.
- Anal spines III.
- Mouth small and lower jaws of breeding males not enlarged.
- Lower pharyngeal bone with long blade in adult, teeth fine.
- Color differences between sexes slight or lacking; no pink areas on chest and belly; "tilapia mark" (a conspicuous dark dorsal spot) present in young only.
- Male genital papilla small and simple.
- Eggs and larvae mouth-brooded by one or both parents; a pair bond is formed at least in some species; no well-marked territorial behavior.
- Absent from rivers entering Indian Ocean, including Upper Zambezi and Okavango, and from western rivers south of Zaïre.

The *Sarotherodon* species most often cultured are *S. galilaeus* (Linnaeus) (Fig. 8A) and *S. melanotheron* Rüppell (Fig. 8B). Occurring in very different areas, these two can be differentiated by: 12-19 lower gill rakers on first arch in *S. melanotheron,* 19-27 in *S. galilaeus;* body color in *S. galilaeus,* silvery to golden yellow, with irregular vertical bars present or absent according to 'mood', while in *S. melanotheron* pearly yellowish to bluish with black patches on chin, lower jaw and shoulder, and with black pigment covering fins or body in some populations.

Eggs are green in *S. galilaeus,* in which both sexes brood; cream to yellow in *S. melanotheron* in which the male usually broods.

S. melanotheron occurs in brackish lagoons and estuaries, rarely in neighboring freshwater or saltwater, from Sénégal to lower Zaïre. Of the five subspecies recognized, *S.m. heudelotii* (Dumeril), in Guinea; *S.m. melanotheron* Rüppell from Côte d'Ivoire to Cameroun; and *S.m. nigripinnis* from Rio Muni to Zaïre are the most important.

S. galilaeus, an important commercial species in many lakes (including Lakes Kinneret, Turkana, Albert and Chad), is a deep-bodied species (depth usually 43-56% SL) usually pale in color with fins uniform or inconspicuously marked, except for pink margin to caudal, some populations with melanin patterns on flanks. Mouth small, lower jaw not exceeding 28% head length, with very small teeth. Pharyngeal bone stout with fine, crowded unicuspid teeth and long anterior blade. Genital papilla of male small and simple.

Of five recognized subspecies, *S.g. galilaeus* is the most widely distributed, from West Africa (including Sénégal to Guinea, Volta and Niger basins), to the Nile and Jordan Valley. In the southern rivers of Côte d'Ivoire and Lake Bosumtwi in Ghana this is replaced by the subspecies *S.g. multifasciatus* (Günther), and in the Lower Zaïre by the subspecies *S.g. boulengeri* (Pellegrin).

The *TILAPIA* Group

The genus *Tilapia* A. Smith is characterized by:

- Low number of gill rakers (6-12 on lower part of anterior arch).
- Pharyngeal bone short-bladed, with coarse teeth.
- Colors bright, very variable and changeable; "tilapia-mark" often persists in adult.
- Eggs are laid on substrate, to which they and early larvae adhere, guarded by both parents who continue to herd the free-swimming fry. Widespread in Africa but not native in Lake

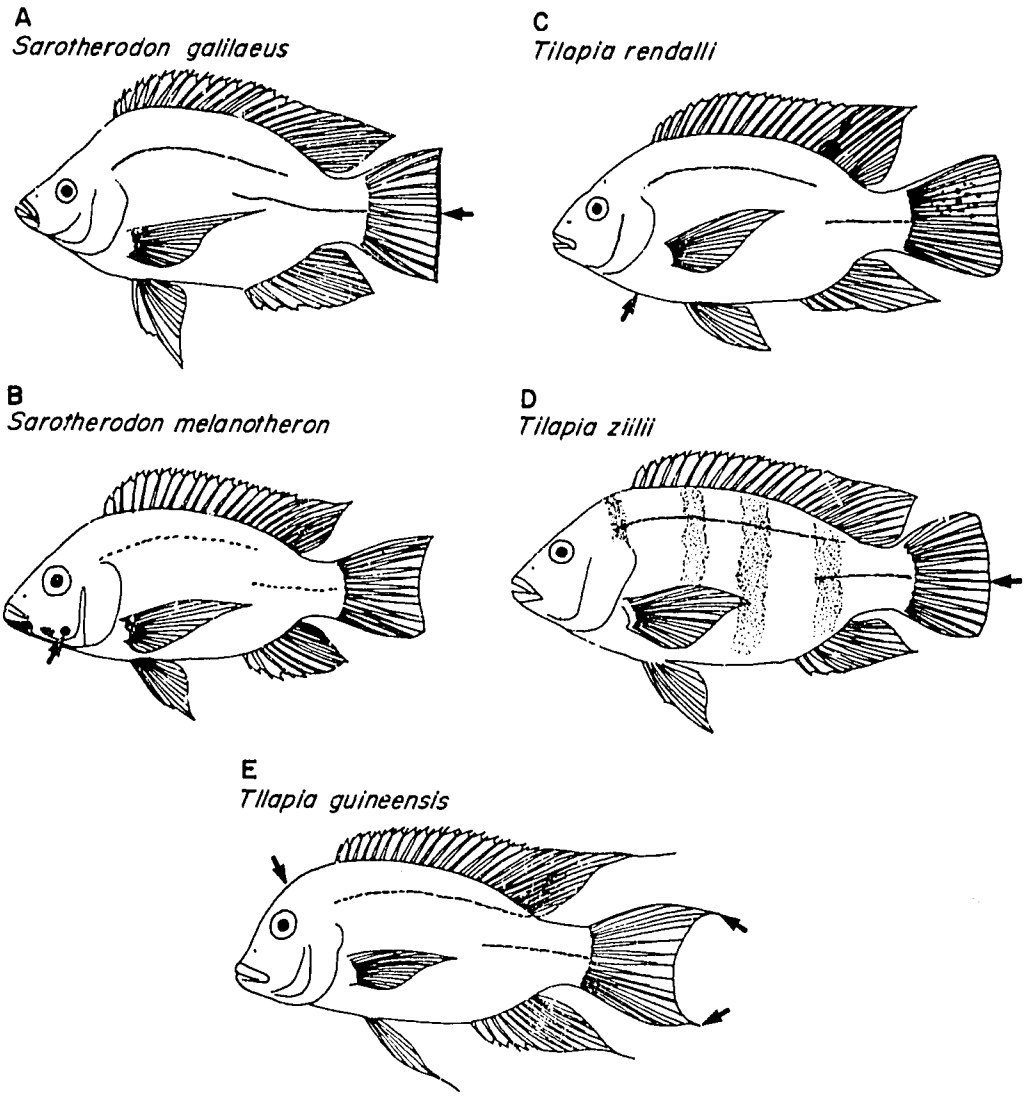

Fig. 8. *Sarotherodon* and *Tilapia* species. Broad arrows indicate major distinguishing characters. A. *Sarotherodon galilaeus*–caudal has pink margin; silvery to golden yellow body; 19-24 gill rakers (outline drawing from Boulenger 1915, fig. 109). B. *Sarotherodon melanotheron*–body color nearly yellow to blueish generally with characteristic black patches on the chin and lower jaw; 12-19 gill rakers (outline drawing from Boulenger 1915, fig. 113). C. *Tilapia rendalli*–caudal truncate; upper half spotted/lower half red (or yellow); tilapia spot on soft dorsal rays often persists; anterior ventral portion of body colored red; 8-10 gill rakers (outline drawing from Jubb 1967. pl. 38). D. *Tilapia zillii*–vertical bars on body; caudal rounded–subtruncate; 8-11 rakers (outline drawing from Boulenger 1915, fig. 126). E. *Tilapia guineensis*–head with high profile; vivid, very changeable colors; caudal outer rays prolonged; 9-10 gill rakers (outline drawing from Boulenger 1915, fig. 128).

Victoria and the eastern rivers of Kenya and Tanzania.

Of the two *Tilapia* species cultured in freshwater, *T. rendalli* (Boulenger) appears to be superior to *T. zillii* (Gervais) as a food fish. The West African *T. guineensis* (Bleeker) lives in brackishwater. *T. rendalli* and *T. zillii* have complementary areas of distribution.

T. rendalli (Fig. 8C) is deep-bodied, both dorsal and ventral surfaces arched (typically deeper bodied than *T. zillii*-Fig. 8D). Caudal truncate (i.e., square-ended, appears cut-off). Eggs yellow.

Body color in adults dark olive-green, darker on back; chest and belly, dull white with black spots mixed with cherry red extending up cheek and lower flanks); lower half of caudal red (yellow), upper half of caudal plain greenish or spotted; dark vertical bars may appear on flanks. In young (ca. 5 cm) *T. rendalli* pelvic fins are orange, in *T. zillii* colorless.

T. rendalli (one of its forms was formerly included in *'T. melanopleura'*, which is no longer a valid name) is widely distributed in the Zambezi system (including Okavango, Upper Zambezi, Kafue, Lower Shire and Lake Malawi), Cunene River (Angola), upper tributaries of Kasai and Lualaba, Luapula, Lake Mweru, Bangweulu region and Lake Tanganyika; introduced into several Tanzanian rivers and dams and Madagascar.

T. zillii usually has two horizontal dark stripes, one midlateral, the other nearer the dorsal outline; these are crossed with vertical bars and the strongest marks are blotches at the intersections; caudal fin covered by a grey network with pale interstices; caudal rounded-subtruncate; eggs green.

T. zillii is a Soudanian form, extending from West Africa through the Chad basin to the Nile, Lakes Albert and Turkana and into the Jordan Valley.

T. guineensis Bleeker (Fig. 8E) usually has profile rising steeply, back arched and ventral outline nearly horizontal. Colors very bright and conspicuous with juxtaposition of dark blue-green, brassy green and intense black and bright cherry pink areas on lower parts of head and body; great changes of color with reproductive and physiological states. Distribution: West Africa, occurs together with *S. melanotheron* in brackish lagoons along the coast from Gulf of Guinée to Lower Zaïre.

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