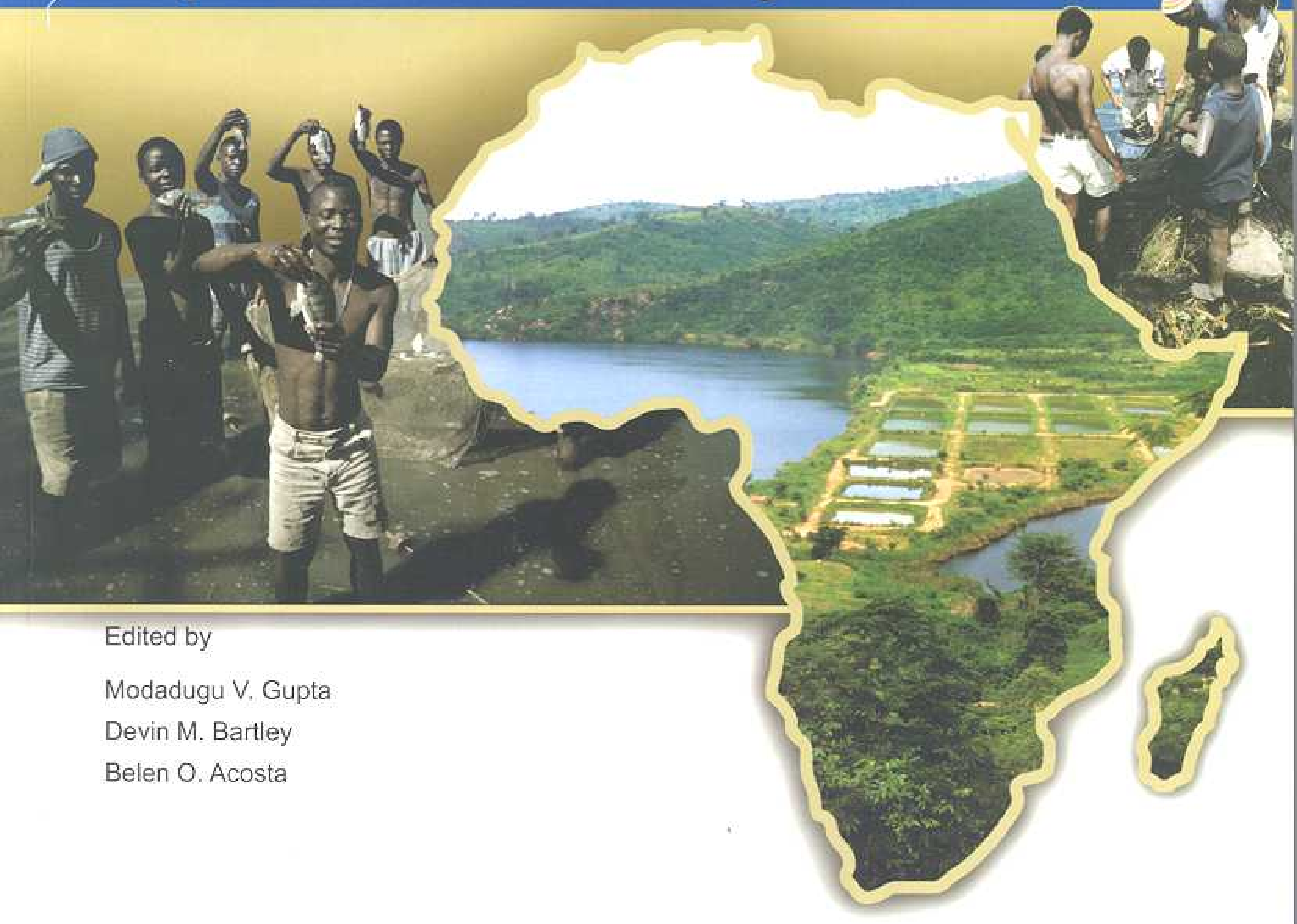
Use of Genetically Improved and Alien Species for Aquaculture and Conservation of

Aquatic Biodiversity in Africa



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IUCN The World Conservation Union

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WorldFish Center

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

Contents

Foreword

In response to major challenges faced by the developing world today on food insecurity and malnutrition, greater efforts are being made to domesticate new species and improve production traits of commercially important aquatic species. In many developing countries particularly in Asia, national breeding programs for major aquaculture species have been established with some of the improved fish approaching commercialization and widespread dissemination stage. While significant progress has been achieved in this aspect, developing countries are also confronted with concerns about the potential impact of introductions of improved fish and other alien species particularly in Africa, a region known for its rich diversity in freshwater fish. The concern expressed by environmentalists centers on potential negative ecological and genetic implications of introduced species on wild genetic resources due to interbreeding of domesticated stocks with populations from the wild.

In view of the risks associated with indiscriminate introductions, the governments of African countries are now faced with the challenge of ensuring the enforcement of biosafety regulations/guidelines and of achieving the participation and full cooperation of sectoral institutions and key stakeholders. These include not only the public sector institutions (national, regional and international) responsible for issues pertaining to the introduction/release of improved or alien invasive species, but also the private sector groups.

To increase the benefits of aquaculture while protecting the environment/native biota, there has to be better recognition by all sectors/stakeholders of the interdependence of genetic enhancement and genetic conservation. The "Expert Consultation on Biosafety and Environmental Impact of Genetic Enhancement and Introductions of Improved and Alien Species in Africa" held in Nairobi, Kenya during 20-23 February 2002 is a significant step to enhance awareness among African institutions, agencies, planners of the issues involved in improving production through introductions of improved strains/alien species while sustaining the biodiversity.

I recommend the proceedings of the consultation presented to you. You will find it a useful tool as these provide valuable information on the status and potential for genetic improvement, introductions and risks of introduced/alien species, and tools and policies for introductions and transfers of these species.

Meryl J. Williams
Director General
WorldFish Center

Preface

Africa's population has grown from 200 million to 500 million in 30 years and is projected to grow to 2 billion by 2050. With the rapid increase in population growth, the region has been the focus of great concerns for food security. Per capita food availability remains the lowest, at an average of 2 100 kilocalories per day. Over 200 million people suffer from chronic malnutrition. It is projected that at current levels of consumption, without allowing for additional imports of food, Africa would have to increase food production by 300 per cent to provide minimally adequate diets for 2 billion people by 2050.

The majority of African populations have traditionally relied on fish, derived mainly from capture fisheries, as the primary source of animal protein in their diet. Fish represented more than 50 per cent of animal protein consumed by developing countries during the mid-1990s and some African countries fall into this category. However, for Africa as a whole, fish availability has declined, and in some countries (for example Ghana, Liberia, and Malawi), the average diet contained less fish protein in the 1990s than it did during the 1970s. Fish catches from the wild are declining due to land and catchments degradation brought about by the rapid increase in population and human activities and over-fishing. Under this situation, a growing number of African farmers consider aquaculture as an option for improving food production and farm income.

Unlike in Asia, aquaculture in Africa has only been slightly exploited to meet the needs of the growing population. The total aquaculture production in Africa in 2000 was estimated at 392 213 t and contributed only about 1.1 per cent of the global aquaculture production. Tilapia accounts for about 40 per cent of aquaculture production in the region. To realize the potential for aquaculture to contribute to food security and compensate for the low growth of capture fisheries, productivity in African aquaculture needs to be increased, made more efficient, and sustainable. Hence, a growing number of African nations are examining ways to achieve this. While there is room for increasing aquaculture production through better farm management, the increases in production needed to meet the demand will require the use of genetically improved and/or better fish breeds, as has been the case in crops and livestock.

Genetic improvement of tropical fish has recently begun to help increase productivity from aquaculture and enhance benefits to the farming community. Studies undertaken in Asia have clearly indicated that production from aquaculture operations in tropical countries could be substantially increased through selective breeding of major aquaculture species. Recognizing the potential of this, efforts are now underway in various parts of Africa to domesticate new species for aquaculture and improve fish production through genetic enhancement.

Africa is the world's repository of diverse freshwater fish fauna and home to native tilapias. The region has 7 502 freshwater fish species distributed in natural water bodies of 48 countries. It also boasts of large natural and man-made lakes, which are important fish and conservation areas. Lake Nyasa, for example has the highest species diversity of any lake in the world, while Lake Tanganyika has a greater diversity of fish families and, in terms of genetic diversity, is the richer lake.

Genetically improved fish developed through selective breeding and other genetic improvement technologies have been projected to bring socio-economic benefits, especially to poor farmers. However, despite these benefits, there might be risks associated with intentional and non-intentional introductions of the improved fish into natural waters. Hence, while there is an urgent need to enhance fish production by developing improved fish breeds, it is also imperative that valuable genetic resources and biodiversity are conserved and protected.

In view of this, African scientists and international organizations involved in aquaculture development and biodiversity conservation felt that guidelines that will help foster the development of aquaculture while maintaining biodiversity and sustaining capture fisheries were necessary.

Bringing awareness among African institutions, agencies, planners of the issues involved in improving production through the introduction of improved breeds and alien species while sustaining biodiversity is the first crucial step in this process. In view of this, the WorldFish Center in collaboration with the Technical Center for Agriculture and Rural Cooperation (CTA), the Food and Agriculture Organization of the United Nations (FAO), the World Conservation Union (IUCN), United Nations Environment Programme (UNEP) and Convention on Biological Diversity (CBD) organized an "Expert Consultation on Biosafety and Environmental Impact of Genetic Enhancement and Introduction of Improved and Alien Species in Africa" during 20-23 February 2002 in Nairobi, Kenya, to bring together fishery and conservation experts, resource managers, geneticists and policy-makers from African countries (Cameroon, Cote d'Ivoire, Ghana, Kenya, Malawi, Nigeria, South Africa, Tanzania, Uganda, and Zambia), advanced scientific institutions, and regional and international organizations to discuss ways to increasing production without compromising biodiversity conservation.

This proceedings volume reviews the potential and constraints for aquaculture development in Africa, the status and potential for genetic improvement, introductions and risks of introduced improved and alien species, and tools and policies for introductions and movements of improved and alien species.

We gratefully acknowledge the financial support provided by CTA, FAO and IUCN and the International Livestock Research Institute (ILRI), Nairobi, Kenya for providing the venue for the meeting. Special thanks are also due to the paticipants for their invaluable contributions in the discussions.

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Opportunities and Challenges for African Aquaculture

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Abstract

Starting from a small base, aquaculture production in Africa registered annual growth rates equal to or above those in other regions. This expansion was due to significant increases in a few African countries. Increasing demand coupled with rapidly dwindling catches from capture fisheries, the implementation of novel participatory approaches to technology development and transfer, and the emergence of a few successful large-scale tilapia culture operations directed at the export market offer opportunities for further expansion in both the small-scale and large-scale commercial sectors. Existing biotechnical, economic and institutional challenges, which include lack of national policies to guide aquaculture development, unfriendly investment policies, the absence of linkages between farmers, research/technology development and extension, and unfavorable investment climates, are currently being addressed in a number of African countries. Long-term economic sustainability of African aquaculture will depend on the development and implementation of national policies that ensure the social and environmental sustainability of the industry.

Introduction

Africa has big potential for fish farming with 37 per cent of its surface area suitable for artisanal and 43 per cent suitable for commercial fish production (Aguilar-Manjarrez and Nath 1998). Although Africa contributed less than 1 per cent to global aquaculture production (251 000 t in 1999), the production has been expanding since 1984 at a rate equal to or greater than the global rate, albeit from a much smaller base (FAO 1997). If the statistics are to be relied, over 90 per cent of reported aquaculture production comes from Egypt and Nigeria. Madagascar (6 000 t) and Zambia (4 000 t) add another 4 per cent. The rest of the continent combined, contributes less than 5 per cent to overall output (FishStat 2001). Unfortunately, these figures are probably not very accurate. Institutional motives for over-reporting combined with inadequate/poor data collection and analysis leave us with a very fuzzy image of the actual status of aquaculture sector in Africa. Reliability of statistics could be improved from personal interviews with government officials and farmers, along with direct observation of the situation on the ground. The current status of African aquaculture as stated in the paper is based on such personal knowledge, combined with the findings of a review of the subject recently done by the Committee for the Inland Fisheries of Africa (CIFA) in consultation with a variety of stakeholders (FAO 2000).

Traditional Aquaculture

The contribution of traditional African aquaculture systems to overall production is not well documented. These systems are believed to have arisen independently in different regions particularly in floodplains and lower courses of rivers characterized by seasonal cycles of flooding and drought and include the damming of natural depressions, drain-in ponds and brushparks (ICLARM-GTZ 1991). These systems are common in West Africa and in the Nile Delta and typical production ranges from 0.1 to 3.8 t/ha/year (Table 1).

Drain-In Ponds

Drain-in ponds are mainly found in the Nile Delta and West and Central Africa. There are two major types of drain-in ponds: *ouedos* and *ahlos* of West and Central Africa, and the *hoawash* (Figure 1) which are mainly found in the Nile Delta. Both types of drain-in ponds are used to culture tilapias.

The *ouedos* are used by people living in the Ouémé valley of Benin to catch fish when floodwaters recede in the floodplain (Nzamujo 1995). Fish holes are also used in the deltaic floodplains of Cameroon (Balarin 1985). The fish holes, which are 50 to 1 500 m long and 4 m wide, are constructed from natural water channels and are deepened to about 1.5 m below the dry season water table (ICLARM-GTZ 1991). Fish, predominantly tilapias, enter naturally into the fish holes during the wet season and are trapped as floodwaters recede. The fish are then harvested using nets or mobile reed barriers.

During the dry season, animals graze in the fish holes and their manure fertilize the fish holes (Nzamujo 1995). The *ouedos* are integrated with agriculture in Benin where maize is cultivated in the drawdown areas between ponds and vegetables are cultivated on the banks around the drawdown areas (Welcomme 1983).

Ahlos are fish holes with tree branches inside to provide refuge and food for the fish. The *ahlos* are a combination of the brushparks/*acadjas* and *ouedos* (Welcomme 1971). The problems faced by these systems include population growth, deforestation due to cutting of trees to provide branches for the *ahlos*, accumulation of undecomposed branches which reduce water flow and the indiscriminate harvesting of smaller fish thus reducing recruitment into the rivers and lakes (Nzamujo 1995; Welcomme and Kapetsky 1981).

Brushparks

Brushparks (Figure 1) consist of branches, bushes or other soft vegetation stuck into muddy bottoms of lagoons, lakes or rivers (Welcomme and Kapetsky 1981). Brushparks are used in various parts of the New World, for example Ecuador, Madagascar, Malawi, Mexico, Bangladesh, Indonesia, and West Africa (Welcomme and Kapetsky 1981; Kapetsky 1981; Williamson 1972). In Africa, brushparks are common in West Africa where the black chinned tilapia *Sarothederon melanotheron* constitutes about 60 per cent of the species caught from the brushparks. Brushparks are extremely productive (Table 1) and their yields, which range from 5 to10 t/ha/year are comparable to modern intensive aquaculture operations (Welcomme and Kapetsky 1981). The high productivity of brushparks is attributed to high nutrient loading resulting frm the decomposition of the wood in the brushpark. The brushwood and branches in the brushpark also act as a growth substrate for epiphytic algae, attract insects and provide breeding sites for fish.

Attempts have been made to improve the management of brushparks in Benin through the stocking of Nile tilapia *(Oreochromis niloticus)* and the use of conventional feed instead of

Figure 1. A brushpark in a lake in Nigeria (top) and a *howash* in the Nile Delta, Egypt (bottom)

using branches to promote and attract food. However, high costs associated with setting up the enclosures and supplementary feeds have made it difficult for local communities to adopt the technology (Nzamujo 1995).

Brushparks compete with adjacent capture fisheries by attracting the juveniles from the open water to the brushpark, and there is also competition for space and resources. Brushparks contribute to local deforestation and environmental degradation as well (Welcomme and Kapetsky 1981). To minimize deforestation and accumulation of organic matter in the system, Hem and Avit (1996) used bamboos, which last up to six years compared to soft wood branches that need to be replaced annually. The conflict between the brushparks and capture fisheries is exacerbated when the brushpark is used as a fish aggregation device. This occurs when harvesting is undertaken at short intervals (three months), thus not allowing the fish to breed and grow inside the brushparks. (Hem and Avit 1996). The prolific spread of brushparks in Benin has also been shown to result in serious social conflicts between brushpark owners and navigators (Pliya 1980).

Introduced Culture Systems

Most African aquaculturists use culture technology imported from Asia, Europe and

North America as part of rural development projects. Most of these are based on earthen ponds. According to King (1993), over 90 per cent of cultured fish in Sub-Saharan Africa come from earthen ponds of 200 to 500 m^2 fed with locally available, low-cost agricultural by-products. In general, the production from these ponds is input-limited, both in terms of quality and quantity resulting in yields of 1 000 to 2 000 kg/ha/year. However, these ponds are multiple purpose facilities for the farming households rather than just for fish production (Brummett and Noble 1995). Field studies have indicated that a good percentage of the fish grown in such systems are bartered or consumed directly by the farm households and so never enter the cash economy (Brummett and Chikafumbwa 1995). Almost all of these fish are disposed of on the pond-bank within minutes of harvest, a finding that might mean that actual fish production in Sub-Saharan Africa is much more than that reported in official statistics.

Commercial systems in Africa are few in number and idiosyncratic, making analyses of systems and trends rather difficult. In Zambia, commercial pig-fish systems routinely produce yields of up to 5.4 t/ha. For example, the Kafue Fisheries Company in Zambia, which at 1 870 ha is the largest integrated fish farm in Africa, covers 37 ha of water and produces 1.5 t/week of 180 to250g sized fish of mostly indigenous tilapias *(O. andersonni, O. mossambicus, O. niloticus, Clarias gariepinus* and *Cyprinus carpio)*. Production is sold in Lusaka (the Zambian capital) at 3 000 Zambian Kwacha per kg, equivalent to about US$0.81 (Lally 2000; Edward Lally personal communication). Other animals produced on the farm are pigs and ducks.

In Egypt, where aquaculture is reputed to be a booming industry (Wassef 2000), producers in the Fayoum depression south of Cairo are typical. These farmers operate 1 to 2 ha earthen ponds, producing primarily *O. niloticus* and mullets (a mixture of mostly wild-caught *Mugil cephalus* and *M. lazera*), sometimes with aeration. New hatchery systems developed in Asia have been built by private investors to permit the use of sex-reversal technology (Figure 2). Pelleted diets manufactured locally by animal feed companies are used to achieve fish standing stocks of up to 3 000 kg/ha/cycle.

Raceway or tank systems (Figure 3) are less common than ponds, but in situations where water is either available by gravity or is being pumped for other purposes, these can also be profitable. On the Namibian coast, oysters are being raised in evaporation raceways operated by a salt export company and are sold to restaurants to increase the economic efficiency of the salt enterprise. Likewise, Baobab farm in Mombassa, Kenya has been operating since the early 1970s with water pumped to supply the Bamburi Cement Plant. The Baobab system incorporates novel circular spawning tanks that can produce up to 60 000 fry of 2 g each per month. Growth rates of about 1.5 g/day can produce 250 to 400 g market sized tilapias in eight to nine months.

Table 1. Summary of the characteristics, inputs and expected yields of selected traditional extensive African aquaculture systems (ICLARM-GTZ 1991).

System (Dimensions)	Essential Inputs	Accessory Equipment	Time to Harvest	SeedStock	Extrapolated Yield (t/ha/year)
Damming; Depressions (≥ 1ha)	Excavation, supplemental feed	Nets	Various, often unregulated	Adventitious entry of wild stock	0.25-0.5
Drain-in Ponds					
Howash (1-20ha)	Earthen dikes, pumping, manure, feeds	Pump, boat, nets	1-10 yrs	Adventitious entry of wild stock	0.5-4.5
Ouedos (20-1250m trench)	Excavation	Net/traps	4 mos	"	1.0-2.1
Ahlos(30m trench)	Excavation, branches	Net	1 yr	"	1.0
Brushparks					
Acadjas	Branches	Canoe, Nets	1-6 yrs	"	4-20
Adokpo	Branches	Canoe, Nets	4-8 mos	"	8-10
Barachois	Stone wall	Seine net	1 yr	"	0.1

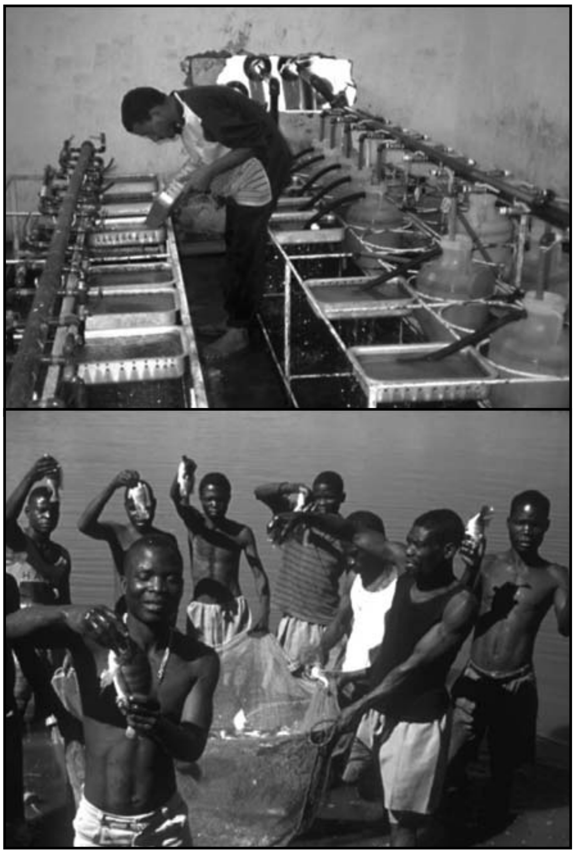

Figure 2. Improved hatchery systems for pond farming of tilapias on a privately owned farm in Egypt (top) and the employment potential of a pond-based tilapia farm in Malawi (bottom).

Feeds manufactured from local by-products are used. Regular grading to ensure that only the fastest growing individuals are maintained is a key to the success of the operation. The culls are fed to crocodiles, the skins of which add to the profitability of the system.

Raceways are also being used in Zimbabwe for outgrowing tilapias (*O. niloticus*) from 50 g to about 700 g in eight months (Windma'r et al. 2000a). A raceway 650 m long with average water flow rate of 1.7 m^3 per second in the Zambezi River is employed to produce 480 t of whole tilapia. The raceway facility in Zimbabwe also incorporates a recirculating system for a pond and tank-based hatchery unit. The tilapia is processed into fillets and are exported fresh or frozen to the European Union Market. Raceways are also being used in Kenya to produce *O.niloticus*. Balarin and Haller (1979) reported that 10 x 1.5 x 0.4 m deep raceways were being employed to rear fry. The raceways used water from production tanks where the water was exchanged at three to four times of the water volume per hour. The fish were fed a 22 per cent crude protein diet and harvests of 22.5 kg/m^3 were attained.

Figure 3. Trout farm in Zimbabwe (top) and an oyster farm integrated with a salt production facility, Namibia (bottom).

Cage culture systems, which exist as pilot or fully operational systems in Southern and West Africa, have so far not significantly contributed to overall production. For example, in 1992, cage culture systems contributed about 2.5 per cent to the total tilapia production (7 755 t) in Nigeria (Ezenwa 1994). Cages are usually made out of wire mesh and securely locked to avoid losses from crocodiles, which are prevalent in most African lakes, rivers and reservoirs. While not much information is available on cage culture in Africa, existing data indicate that low lake levels adversely affect the cage culture of tilapias. The high cost of production makes them an uncompetitive, cheap imported marine species (Marshall and Maes 1994). Returns to small-scale cage culture have also been reported to be unpredictable and dependent on the cost of fingerlings, feed (which can amount to 60 to 70 per cent of the total cost) and the fish itself (Marshall and Maes 1994). There are, however, a few successful cage culture operations in Africa. The largest is in Lake Kariba with an annual production capacity of 2 000 t of whole tilapia (Windmar et al. 2000 b). Other countries in Africa such as Malawi and Kenya have either established some tilapia cage culture operations or are in the process of establishing these facilities.

Challenges and Opportunities for the Future

The entry of African aquaculture into global prominence faces considerable challenges. There are, however, reasons for optimism. Despite high risks and investment costs, high and increasing demand and market value of fish are encouraging. If social and environmental sustainability issues can be successfully addressed, increasing market demand and higher prices should open opportunities for a range of producers and investors. Increasing productivity of both large and small-scale aquaculture will require major investments in research, development and extension (see below) as well as policy shifts. The strategies for addressing problems of the small-scale and larger commercial operations will probably be different.

Improved Systems

The majority of beneficiaries of aquaculture development projects have been rural small-holders operating mixed farming systems in which aquaculture plays a more or less minor role compared to staple crop production. It is impossible to determine the total output of these farms, but continent-wide they number in the hundreds of thousands. These farmers lack both the knowledge and means to break into commercial aquaculture. However, as they are by far the largest and most needy group of African farmers, the equitable distribution of the benefits from aquaculture development will require approaches that cater to their needs.

Such options as integrated farming where animal and crop residues and by-products are used as feeds in a fishpond can help to overcome material constraints. The use of participatory strategies for technology transfer may be important in the building of capacity within this group. Traditional aquaculture systems that are widely practiced in some parts of West Africa offer future opportunities for increasing small-scale tilapia production in other parts of Africa (Machena and Moehl 2000; ICLARM-GTZ 1991). However, research on improved practices, community management and tenural rights are needed to increase productivity and assess the possibilities for their commercialization.

Table 2. Major constraints to commercial aquaculture in Sub-Saharan Africa (Brummett and Williams 2000).

- Generally poor infrastructure
- Essential inputs lacking or difficult to access
- Political instability
- Cash-limited local markets
- Poor quality/quantity extension services

Hecht (2000) suggests that donor funding on aquaculture production, which targeted the "poorest of the poor" had been misdirected and proposes the targeting of small-scale entrepreneurs in this sector in order to increase productivity. However, successful commercial farming systems in Africa are not easy to characterize as being more successful than small-scale projects. Many commercial systems are relatively small or pilot-scale operations, focused on producing high value species for export. Their viability often relies on idiosyncratic circumstances and is often short-lived. The main constraints to commercial aquaculture (Table 2) are common to most agro-industries in Africa. Generally poor infrastructure such as poor telecommunications, bad roads, irregular air services and unreliable electricity means that many types of equipment will not function when they are most needed; thus it will be difficult to store fish for any length of time and many markets will be inaccessible. The lack of essential inputs such as feeds, fertilizers, chemicals, fuel and spare parts or their volatile prices severely restrict a farmer's ability to predict yields and make any sort of reliable economic forecasts. Political instability has been Africa's bane for many years and can threaten not only the economic viability of an enterprise, but has also claimed the lives of investors and farm managers. The general poverty of African communities, and their consequent reliance on barter, is why most commercial farms look to external markets. Lack of expertise, both in the extension services and among potential farm managers, means that production systems must be easy to operate. Since many commercial farms make their profits on the margin of systems that are being pushed to their limits, having to rely only on safe technology severely restricts the range of economically viable enterprises that can develop.

There is scope to increase tilapia production from large-scale commercial systems both for domestic consumption and for export. Currently, only a few African countries such as Zimbabwe, Uganda and South Africa are exporting tilapias to Europe and the United States of America (Windmar et al. 2000 a; American Tilapia Association 2001). Tilapia exports from Uganda to the United States market are likely from capture fisheries, since Uganda does not have a developed commercial aquaculture sector. The success of Zimbabwe tilapia producers in profitably producing tilapias for the export market suggests that this sector could significantly contribute to tilapia production in Africa. The major challenges facing the development of large-scale commercial tilapia farming are environmental sustainability in the face of unregulated importation of exotic fish species and their hybrids, access to capital, poor infrastructure to maintain the cold chain necessary for exporting high value perishable commodities, and the availability of cheap feeds. Most of the ingredients used in commercial tilapia diets are imported and customs duties make their prices prohibitive. As for the small-scale sector, enabling policies are required to further develop tilapia production by large-scale commercial farmers. Some African countries have or are in the process of removing import duties on capital equipment and supplies used in the aquaculture sector.

Germplasm

Artisanal producers typically grow indigenous tilapias (mostly *O. niloticus* and *O. mossambicus*) and African catfish (*C. gariepinus*), although the parental lines for cultured populations often originated outside of the basins or even the countries in which they are currently being grown (Pullin 1988). Of 212 freshwater fish introductions for African aquaculture, only 33 (16 per cent) resulted in the establishment of an industry with output of more than 10 t/year in 1997 (Brummett 2000a; FishBase 2001; FAO 1999). Of the introductions that resulted in the establishment of an industry, 10 (30 per cent) were of *C. carpio* from Asia and Europe and 7 (21 per cent) were of *O. niloticus* from other African countries. The balance was of mixed cyprinids and rainbow trout (*Oncorhynchus mykiss*).

This situation may, however, be changing, particularly in commercial systems. For example, over 20 years of regular culling (a form of uncontrolled selective breeding) at Baobab in Kenya has led to the creation of a Baobab strain of *O. niloticus.* Recently, a mixture of *O. niloticus* and *O. spilurus* broodfish were imported from Lake Turkana to diversify the stock. Genetic introgression among these stocks is likely.

At Kafue, most production is based on the indigenous *O. andersonii* and *O. mossambicus*. In the last few years, imported *O. niloticus* have been added. At Lake Harvest, Zimbabwe introduced *O. niloticus* are the main cultured species.

The management of non-native and/or improved species is a major challenge for African aquaculture. Pressures from producers have led to the introduction of *O. niloticus* from other African countries for culture in large-scale commercial systems in Zambia and Zimbabwe, and elsewhere interest in tilapia hybrids and YY "supermale" tilapias is increasing. Although guidelines for the importation of alien fish species exist (for example. FAO Code of Conduct for Responsible Fisheries), weak regulatory mechanisms, the absence of policies and understaffing in most African countries do not allow the enforcement of regulations regarding the importation and management of exotic species. Environmental sustainability with respect to alien species can only be achieved if regulations on the importation and use of alien tilapias are enforced and systems are managed according to accepted best management practices to minimize the impact of escapes on local biodiversity. This is also true with respect to effluent from large-scale commercial tilapia farms.

Research, Development and Extension

Although the majority of the systems used in African aquaculture were introduced through technology development and transfer projects, the current state of most research, development and extension (R, D & E) in Africa is poor. Low levels of annual expenditure have rendered national and regional programs more or less incapable of managing the growth of the industry. A large percentage of governmental aquaculture facilities are either abandoned or dysfunctional for various reasons (FAO 2000). Despite a number of projects aimed at introducing multi-disciplinary, holistic and participatory approaches, aquaculture extension remains very much top-down and poorly trained. In terms of human resources, extension, arguably the most difficult aspect of technology development and transfer, is normally the entry-level position to government service and, hence, is normally staffed by inexperienced and/or poorly motivated personnel (van der Mheen 1999).

To provide needed support to the development of aquaculture, Coche et al. (1994) recommended a thorough overhaul of the R, D&E system in Africa. In particular, governments should: (i) provide adequate training for both research and extension and; (ii) develop information systems that can systematically provide farmers with access to technology.

In these times of structural adjustment and fiscal austerity, neither of these suggested changes has been broadly implemented. In fact, most African states are dropping aquaculture from their funding portfolios without any provision for either future support to the industry, or its regulation. For example, a working group on aquaculture development in Africa recently agreed to recommend to their respective governments a plan that would:

- Privatize at least half of government aquaculture facilities by 2004.
- Transfer to Fish Farmer Associations and NGOs the main responsibility for the majority of services now provided by the government (such as fingerling production, breeding programs, feed formulation, technology adaptation, and demonstration.)

Individual private operators are thus being put in the position of choosing the type of production system that will guide investment and the type of germplasm to be used. Unfortunately, in Africa's uncertain investment climate, high-risk/short-term profit systems are favored. Some common features of these systems render them socially and/or environmentally unsustainable:

- An export-orientation that can actually reduce local availability of fish. For example, high-value shrimp farms built in mangroves, using locally produced fishmeal.
- Importation of trained expatriates, reducing job and training opportunities for local technicians.
- Use of high external inputs, sometimes imported, that keeps prices high and can have negative environmental consequences through eutrophication.
- Use of alien species or hybrids that once escape to the wild, often have negative impacts on indigenous species and ecosystems.

The development and dissemination of information, and the implementation of participatory approaches that target the different needs of a wide range of farmers could solve some of the technological adoption problems facing aquaculture production in Africa (Brummett and Williams 2000; Harrison 1994). New approaches that employ a participatory approach to technology development and transfer for production of tilapia and other aquaculture species offer new opportunities for increasing production of small-scale tilapia ponds. The participatory approach to technology development and transfer allows farmers to be part of the technology development process, and in so doing farmers gain a greater understanding of the functioning of their production systems and are better able to guide the system towards greater productivity (Brummett and Williams 2000). Of course, such a radical change in how aquaculture research and extension is conducted requires the commitment of government policy-makers and the formulation of appropriate policies that will allow such shifts in technology development and transfer approaches to occur. However, in most African countries, aquaculture policies to guide the development of aquaculture production are non-existent (FAO 1999; Machena and Moehl 2000). The institutional changes that are occurring with respect to technology development and transfer, and the removal of the constraints to aquaculture development alluded to earlier, require African governments to develop policies that address the existing constraints.

Table 3. Prices for farmed tilapias from selected African countries.

Country	Year	Price (US$/kg)
Egypt	2001	1.50 (100-200 g) 1.90 (>200 g)
Malawi	2001	1.00-1.50 (all sizes)
Nigeria	2001	0.83 (100-200 g) 1.00 (>200 g)
Zambia	2001	0.83 (220 g)

Markets

Local demand for aquaculture products in many African countries is high and is projected to increase in the future. For example, in Malawi, fish produced in rural areas are sold out the day before harvest, and local demand for tilapias is so great that pond fish rarely reach the urban markets. In Zambia and Egypt, most of the production is targeted towards urban markets, which absorb all the premium high value fish, the remainder being sold locally. Table 3 presents tilapia prices for some selected African countries.

Tilapia prices are generally high and depend on the size and/or quality (freshness) of the fish. For example, in Nigeria, Uganda and Egypt large-sized pond fish (200 g) are sold at higher prices compared to small ones (100 g) (Adesulu 2000; Afolabi et al. 2000; Gamal El. Nagar personal communication). In Malawi, however, fish size does not affect the price of tilapias, although freshness has an impact (Brummett 2000b). Rapid urbanization and population growth, especially in Sub-Saharan Africa, is likely to increase demand for fish in the future. If the constraints to the development of socially and environmentally sound aquaculture described above can be overcome, the economic viability of fish production should be assured for many years into the future.

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Genetic Improvement with Specific Reference to Tilapia Genetic Resources in Africa and Their Use in Aquaculture-Potential Benefits and Risks

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Abstract

In comparison to the rest of the world, aquaculture in Africa is fairly insignificant. The continent as a whole contributed a mere 0.9 per cent (404 571 t) to the total world aquaculture production in 2000. The African continent, however, exhibits considerable potential in terms of land and water and in regard to inland, coastal and offshore resources. Genetic improvement of tilapias has a role to play in order to increase aquaculture production. Promotion of such methods as selective breeding, hybridization, chromosome manipulation and gene transfer will help in improving aquaculture production. However, there are controversial issues that must be addressed so that genetic improvement should not compromise the conservation of biological diversity in the wild as well as in aquaculture. This is particularly important for tilapias in Africa where the species are indigenous and need to be conserved. Simple selective breeding of indigenous species within their natural zoogeographical zones would, therefore, offer great opportunity in African aquaculture, so that yield improvement is attained without causing significant genetic deterioration of the wild populations.

Introduction

Fish is an important source of protein to more than one billion people in the world. It supplies about 30 per cent of the total protein intake for people in Asia, 20 per cent in Africa, and 10 per cent in Latin America. The fish industry employs 150 million people around the world and about 40 per cent of fish production is traded internationally. In the last decade, fish production has declined and the price of fish has gone up. In attempts to mitigate the price increase crisis, efforts are underway to develop methods of increasing fish production through aquaculture and to embark on sustainable management of wild stocks and the environment. This is important considering that the projected world demand for food fish for the year 2010 is estimated at 105 to 110 million t as against a production of 94 million t in 1997 (FAO 2000). The contribution of aquaculture towards world fisheries has increased from 11.4 per cent of the total catch in 1984 to 30.1 per cent of the catch by weight in 1998. In 1998 aquaculture contributed 16.9 per cent of the total finfish landings, 17 per cent of crustacean landings, 56.7 per cent of shellfish landings, and 87.5 per cent of the aquatic plant landings (Tacon 1999). The most important continents in terms of aquaculture production are Asia (74 per cent), Europe (11 per cent), North America (7 per cent), and South America (3 per cent). Developed countries such as those in Europe and North America have a higher contribution in terms of value because these countries are focusing more on the production of high value species. Demand for aquaculture products in North American and European markets has shown continuous growth of 10 to 15 per cent annually, particularly with regard to shrimp, salmon, trout, catfish, and tilapia.

In comparison to the rest of the world, aquaculture in Africa is fairly insignificant. The continent as a whole contributed a mere 0.9 per cent (404 571 t) to the total world aquaculture production in 2000 (FAO 2003). The African continent however exhibits considerable potential in terms of land and water, both with regard to inland, coastal and offshore resources. The expectations are that aquaculture development in Africa will show considerable increase over the medium to long-term due to the increasing demand in the world markets and the availability of resources in the continent.

Countries in the Mediterranean region produce 67 per cent (77 800 t) of the total production for Africa, with Egypt alone contributing approximately 34 per cent (42 000 t). The production in Sub-Saharan Africa amounts to 33 per cent (39 000 t) of the total production for Africa, or 0.2 per cent of world production. The most important countries in the Sub-Saharan region are Nigeria (16 600 t), Zambia (5 100 t), South Africa (5 000 t), Kenya (4 000 t), Tanzania (4 000 t), and Madagascar with (3 300 t) (Pedini and Shehadeh 1997). The main species cultured are tilapia, catfish, carp, cyprinids, mussels, oysters, shrimps, and seaweed.

Tilapia is a major aquaculture species in Africa and Asia and is a suitable species for increasing protein production, profits and the quality of nutrition of poor fish farmers and consumers.

The tilapia originated from Africa but has been spread all around the world in the tropical and subtropical areas because it is hardy, easy to grow, and can be fed with a range of different feeds. Although the tilapias have been distributed so widely outside their natural zoogeographical zone, little attention was given to the genetic improvement of farmed populations and the broodstock outside Africa which had been derived from very small founder populations and mismanaged, leading to genetic drift, inbreeding depression, and introgressive hybridization (Pullin and Capili 1988). The genetic problems of tilapias include: (i) loss of pure species through mismanagement of inter-specific hybridization in trying to produce all-male fry which grow faster than mixed sex populations (McAndrew 1993); and (ii) high level of inbreeding depression because primary collections of wild brood stock frequently consist of a small number of individuals. Kocher (1997) reports heterozygosity loss of less than 10 per cent in the farmed populations compared to the wild counterparts. Negative selection for growth rate has also occurred in the process of propagating many stocks.

Most African countries have erratic or only incipient aquaculture production. Aquaculture investment is generally minimal; there is still dependence on recruiting broodstock from the wild. Owing to small pond sizes and continuous drought regimes, the ponds generally dry out and seed or broodstock are easily lost. Consequently, new genetic material is collected from the wild. Hybridization in the ponds is also common to the extent that strains recruited into the farms easily interbreed. Genetic purity is quickly lost. The small pond sizes and limited supply of fingerlings have resulted in inbreeding in the aquaculture facilities. Farmers usually stock very few fingerlings with the intention that the fish will multiply during the grow-out period.

Genetic Improvement in the Tilapias

Domestication of tilapias is still in the early stages, as the genetic resources have been poorly managed during the past 40 years of intensive and extensive culture systems (Kocher 1997). Several approaches have been used to improve the performance of tilapias in aquaculture and some that have immediate or near future applications in Africa are reviewed below.

Selective Breeding

Selective breeding has been carried out on the tilapias and has now reached advanced stages. In other parts of the world, selection has been done for skin color, body conformation, fillet yield, growth rate, and cold tolerance (Behrends et al. 1982, 1990; Fitzsimmons 2000). In the Philippines, the WorldFish Center and other collaborating institutions carried out selective breeding programs on *O. niloticus* resulting in an improved strain called the GIFT strain, and it is being widely distributed in Asia. Protocols used to develop the GIFT strain are currently being used in Egypt, Cote d' Ivoire, Ghana and Malawi to improve local strains of *O. niloticus* and *O. shiranus*. This work is being carried out in collaboration with the WorldFish Center (Gupta et al. 2001). Small-scale strain comparisons were carried out from 1997 to1999 in Malawi where wild populations of *O. shiranus* grew faster than domesticated stocks. Microsatellite DNA analysis of the populations revealed that farm populations had very low genetic diversity compared to their wild counterparts, mean number of alleles 4.4±1.03 and 13.2±3.31, respectively, and there was introgression of *O. mossambicus* into the *O. shiranus* populations. *O. mossambicus* populations from several water bodies in southern Africa have been recruited for genetic improvement at the University of Stellenboch in the Republic of South Africa.

Hybridization

Hybridization has been adopted as an approach to improve tilapia yields. The cultured tilapia species are closely related and readily produce viable hybrid crosses. Hybrids have also been produced to obtain all-male fry that grow better than mixed sex populations. McAndrew et al. (1988) indicated that one popular strain may contain genes from as many as four species. Heterosis has been observed for such traits as superior growth, feed conversion, cold or salt tolerance, and disease resistance.

Chromosomes-set Manipulation

Chromosome-set manipulation techniques include polyploidy, gynogenesis and androgenesis. These have been applied in fish improvement programs although gynogenesis and polyploidy have been widely applied in tilapia aquaculture compared to androgenesis which has had limited application.

Gynogenesis

Gynogenesis or all-maternal inheritance is a chromosome manipulation technique that ensures the exclusive inheritance of the maternal genome. The egg develops without any genetic contribution from a male parent because the genetic material of sperm is inactivated by exposing the sperm material to radiation (for example x-rays, ã-rays and ultraviolet light) or to chemical mutagens such as toludine blue, dimethylsulfate or tryplavine, without affecting its functional potential to fertilize or activate egg development. The egg development initiated by irradiated spermatozoa is a haploid gynogenetic zygote. The diploidy state can be restored by subjecting the haploid zygote to thermal, chemical or hydrostatic pressure shock treatments (Romana 1988).

If the pressure shock treatment (heat or cold shock) or chemical treatment (cytochalasin B, colchicines, and polyethylene glycol) is applied soon after fertilization to suppress ejecting of second polar body meiotic gynogenes are obtained. Mitotic gynogens are produced by late shock treatment to suppress the first mitotic division, allowing restoration of diploidy. Meiotic gynogens are about 50 per cent inbred due to crossing-over and the recombination, while mitotic gynogens are 100 per cent inbred and can be used for the production of clonal lines (Purdom 1993; Owusu-Frimpong et al. 1997). The gynogenetically induced inbred lines of tilapia are developed for purposes of hybridization to fix desirable production traits.

Production of a single sex group, which can be achieved by manipulating developing gametes or embryo, provides the advantage of exploiting the sexual growth differential phenomenon whereby male tilapias grow faster than female tilapias. The manipulation would include denaturing the DNA in gametes followed by chromosome-set manipulation or hormonal sex-reversal and subsequent breeding. Genetically male tilapia can be turned into females through estrogen treatments. The genetic females when mated with normal males produce a group of all-male tilapia that grow faster and have less unwanted mating than mixed sex stock.

Polyploidy

This technique produces polyploids, triploid or tetraploid organisms that do not invest their energy into reproduction because they do not develop effective reproductive organs. Ploidy manipulation employs the same physical and chemical treatments used in the diploidisation phase of gynogenesis. Alternatively, triploidy can be obtained by mating normal diploid fish with tetraploids. Their main advantage is that they are sterile. In tilapia, triploidy has been advantageous in that it retards gonadal development. Hence, there is an absence of uncontrolled reproduction, which causes stunted growth (Bramick et al. 1995).

Genetic Engineering

Genetic engineering and the production of transgenic organisms have become an active area of research and development in aquaculture. In tilapia, transgenics that contain the exogenous growth hormone (GH) gene construct derived from Chinook Salmon have demonstrated growth enhancement (Rahman and Maclean 1997). The transgenic tilapia grows three times larger than their non-transgenic siblings in a period of seven months. Studies of transgenic technology in tilapias have demonstrated great potential of improving aquaculture production by growing genetically modified tilapias.

Marker-assisted Selection

Use of genetic makers to identify loci that control quantitative traits (QTL) and develop superior strains through marker-assisted selection is still in its early stages in tilapia improvement programs. Work on developing a linkage map in tilapia has been carried out at the University of New

Hampshire, offering an opportunity to track and select desirable genes from the map.

Potential Benefits and Risks

Genetic improvement offers an enormous opportunity for increasing aquaculture production in Africa. It, therefore, implies that each of the techniques discussed above has potential benefits although experience has shown that besides the benefits there are inherent risks associated with them as well.

Selective Breeding

Selective breeding offers great opportunity for aquaculture production in Africa. Most of the tilapia species cultured in Africa have not been adequately domesticated, hence, the application of selective breeding in the domestication process can improve the performance of the strains. The fifth generation GIFT strain of *O. niloticus* is reported to grow 85 per cent faster than other farmed strains and can be grown without commercial feed in extensive systems (Eknath and Acosta 1998). Application of similar protocols on the stocks within Africa would improve the performance of local tilapias. The risks from selective breeding are that it takes a long time to improve a strain and it is costly; consequently, such programs are likely to be abandoned in the African setting where funding for genetic research is limited and labor turnover is high as trained personnel change jobs in search of better remuneration. Instead of countries concentrating on developing their own native genetic resources, there is a tendency to import improved strains developed elsewhere. For instance, *O. niloticus* has been introduced into some African countries such as Zimbabwe and Zambia because the species grows faster than indigenous species. Owing to poor management, some of these introduced strains have escaped into the wild and hybridized with indigenous species. This, therefore, brings in ecological risks whereby the introduced species cross with indigenous ones and produce unbalanced sex ratios. Crossing a female *Tilapia tholloni* with a male *O. mossambicus* yields 100 per cent females and crossing female *O. spirulus* with male *O. leucostictus* yields 98 per cent males (Agnese et al. 1998). There are several cases where farmed populations have escaped into the wild but the results of hybridization are not easily observed. In cases where genetic markers have been used, it has been observed that the genetic purity of the indigenous stock has been lost. In Lake Ayami in Cote d'Ivoire, *T. busumana* and *T. discolor* have been reduced in numbers and even disappeared in catches. Instead, they have been replaced by *Sarotherodon melanotheron*, an introduced species (Agnese et al. 1998). Limited research facilities have also resulted in the risk of deteriorating genetic diversity because only a few individuals are recruited as founder stocks, causing inbreeding. The risk is, however, tolerable in countries where indigenous species are stocked because there is a tendency to recruit wild genetic materials on a more regular basis as the stocks are easily wiped out by drought, floods or predators.

Hybridization

Hybridization can be adopted as a genetic improvement approach to increase performance of the progeny through heterotic and non-heterotic effects. The heterotic effect is increased performance of the progeny above the average of the parents as a result of the simple combination of parental genotypes (FAO/UNEP 1981). Most fish culturists in developing countries breed superior individuals from unrelated strains in order to bring new genes into a selection program. The F_1 hybrids are normally propagated as parental stocks with the assumption that the observed improved growth will be passed on to the subsequent generations. Unfortunately, this does not occur due to segregation and consequent hybrid breakdown in the F_2 generation. Most of the hybrids produced in aquaculture in Africa are unplanned, hence they have not been monitored adequately. For instance in Malawi, hybrids between *O. shiranus chilwae* and *O. shiranus shiranus*, and between *O. shiranus* sp and *O. mossambicus* have been produced unnoticed (Ambali et al. 1999).

If hybridization is chosen as an approach for improving the performance of the indigenous population, there should be well-established genetic characterization records in order to monitor the long-term purity of the parental lines. A great deal of effort is, however, required to breed and maintain these parental lines, yet developing countries cannot afford the costs involved.

Genetic Engineering

There has so far been no commercial farming of genetically engineered tilapias in aquaculture in Africa. However, in places where transgenics have been grown in the laboratory, they have shown higher growth than non-transgenics. Prospects of genetically modified (GM) tilapias being introduced in aquaculture are high because of the need to increase food production in developing countries in Africa and Asia. The concerns being expressed by anti-GMs lobbies may wane with time as the benefits of growing GM tilapias will outweigh the risks involved.

A potential risk of using genetic engineering for improving tilapia populations is that transgenics would make individuals less fit than their wild counterparts by affecting such traits as juvenile survival. But this is only a speculation.

Chromosomesset Manipulation

The advantage of chromosomes set manipulation is that single sex individuals can be produced which may have better growth than mixed sex populations. Production of ploidy fish requires a proper understanding of ploidy manipulation and parental genome inactivation techniques.

The risk of the technique is that it is difficult to attain 100 per cent sex-reversal. The technique has, therefore, met with failure. The other problem is that of obtaining a large number of eggs prior to fertilization, and this is an impediment to large-scale commercial tilapia culture.

Marker-assisted Selection

In marker-assisted selection, it takes a short period to improve performance of individuals in a population as compared to conventional breeding. The problem is the high costs involved in developing linkage maps.

Way Forward

Genetic improvement of tilapias has a role to play in order to increase aquaculture production. The lack of suitable species has been identified as one of the key factors that have affected the adoption of aquaculture in most African countries much as environmental conditions are favorable and water is available. Promotion of such methods as selective breeding, hybridization, chromosome manipulation and gene transfer will help in improving aquaculture production. However, there are controversial issues that must be addressed so that genetic improvement should not compromise the conservation of biological diversity in the wild and in aquaculture. This is particularly important for tilapias in Africa where the species are indigenous and need to be conserved. Simple selective breeding of indigenous species within their natural zoogeographical zones would, therefore, offer great opportunity in African aquaculture so that yield improvement is attained without causing significant genetic deterioration of the wild populations. Modern molecular techniques are becoming more affordable as laboratory protocols become more refined. The DNA probes, especially microsatellite DNA, would be employed in the breeding programs to establish records of family relationships and pedigrees and determine the genetic stock structure of the natural populations.

The introduction of superior strains may not be the most appropriate approach in most African countries where aquaculture facilities are poor and the fish easily escape into the wild.

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Introduction of Alien Species/Strains and Their Impact on Biodiversity

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Abstract

Africa has been the source of alien species that are widely used in aquaculture and fisheries in many parts of the world, but African aquaculture has not benefited greatly either from the domestication of African species or the introduction of improved breed from elsewhere. In efforts to develop African aquaculture further, there is a desire to re-introduce genetically improved tilapia (primarily *Oreochromis niloticus*) back into Africa. However, there are risks to native African aquatic biodiversity that must be dealt within the re-introduction of African species. Analyzing these risks in order to make informed decisions will require, *inter alia,* information; such an information source exists in the FAO Database on Introductions of Aquatic Species (DIAS, http://www.fao.org/fi/statist/fisoft/dias/index.htm). An examination of DIAS revealed that 139 species from 87 genera have been introduced into 42 African countries. Most of these introductions were finfish (79 per cent). However, 7 per cent were molluscs and 9 per cent were crustaceans. Tilapia is the most important species of fish that Africa has contributed to world fisheries and aquaculture. FAO Fishery statistics reveal that tilapias are farmed in 61 countries outside of Africa (33 in Africa) and these alien tilapia account for 2 per cent of the world aquaculture production. In Africa, tilapia accounts for about 40 per cent of the aquaculture production. The impacts from tilapia introductions vary greatly. The information on the impacts of the introduction is poor, but tilapia introductions into Africa had positive socio-economic benefits. There were not many adverse ecological impacts reported in Africa, in spite of the indication that most of the introductions led to self-sustaining populations. Developers concerned with both food security and conservation will need to collect information such as that contained in DIAS, process this into knowledge so that informed decisions can be made, and then develop the wisdom to know when and where to make decisions for the greater good of this and future generations.

Introduction

The use of introduced species in Africa has been called a paradox (Satia and Bartley 1998) because Africa has been the source of alien species that are widely used in aquaculture and fisheries in many parts of the world, but African aquaculture has not benefited greatly either from the domestication of African species or the introduction of improved breed from elsewhere. In efforts to develop African aquaculture further, there is a desire to re-introduce genetically improved tilapia (primarily *Oreochromis niloticus*) back into Africa. Indeed, this desire is also consistent with the Convention on Biological Diversity's intention to share and transfer technology and information (CBD 1994).

However, not all alien species have benefited their new environment; alien species and alien genotypes are now recognized as one of the major threats to aquatic biodiversity. The WorldFish Center, the developers of genetically improved farmed tilapia (GIFT), had a policy of not re-introducing GIFT fish back into Africa because of fears they would pose a risk to the genetic resources of wild tilapia. Thus there must be a balance between development and conservation objectives. Developers, resource managers, and aid agencies need to know how and when to use alien species and genotypes in a responsible manner.

This will not be a simple task. As developers concerned with both food security and conservation, we need to collect information, process this into knowledge so that informed decisions can be made, and then develop the wisdom to know when and where to make decisions for the greater good of this and future generations.

Information

Gathering information is the crucial first step in our process. We need information on the extent of introductions, who was responsible, what were the reasons, and what were the impacts (good and bad). To examine the extent of alien species in Africa, we queried the FAO Database on Introductions of Aquatic Species (DIAS, http://www.fao.org/fi/statist/fisoft/dias/index.htm). Satia and Bartley (1998) reported that 139 species from 87 genera have been introduced into 42 African countries. Most of these introductions were finfish (79 per cent). However, 7 per cent were molluscs and 9 per cent were crustaceans. Focusing on tilapia, this is the most important species of fish that Africa has contributed to the world fisheries and aquaculture. FAO Fishery statistics reveal those tilapias are farmed in 61 countries outside of Africa (33 in Africa) and these alien tilapia account for 2 per cent of the world aquaculture production. In Africa, tilapias represent about 40 per cent of aquaculture production. Tilapia spp have also been moved about within Africa – production from alien tilapia in Africa is also increasing (Figure 1).

The impacts from these introductions vary greatly. In Venezuela and the Great Lake of Cambodia, for example, tilapia appear not to have had any significant influence on native populations. In the Philippines, however, tilapia has displaced local species as well as the commercially important milkfish from coastal ponds (see Pullin et al. 1997). DIAS attempts to document the nature of the impacts of introductions by asking respondents to classify whether the impact was positive, negative or undecided from both ecological and socio-economical perspectives (Figure 2). The information on the impacts of the introduction is poor, but generally it was reported that tilapia introductions into Africa had positive socio-economic benefits. In Africa, there were not many adverse ecological impacts reported, in spite of the indication that most of the introductions led to self-sustaining populations (Figure 3).

Another significant type of information needed is on genetic technologies. That is, how different are the alien species or alien genotypes from the wild relatives? Tilapia has been genetically improved through selective breeding programs, such as the GIFT program (Eknath et al. 1993), primarily through hybridization (see review in Bartley et al. 2001) and through the application of sex reversal and chromosome set manipulation (Mair et al. 1997). The use of gene transfer technologies is currently being studied, for example in the USA, the United Kingdom and Cuba.

Knowledge

One definition of knowledge is "an organized body of information" (Oxford American Dictionary 1979 Oxford University Press); DIAS, FishBase, and FAO statistics do represent knowledge in this regard. But we believe more is needed to be knowledgeable, that is, to use the organized body of information as a decision tool. Risk/benefit analysis is one means to move towards knowledge on how and when to use alien species.

Risk assessment will need to examine both ecological and economic factors. Categories of ecological risk include species interactions,

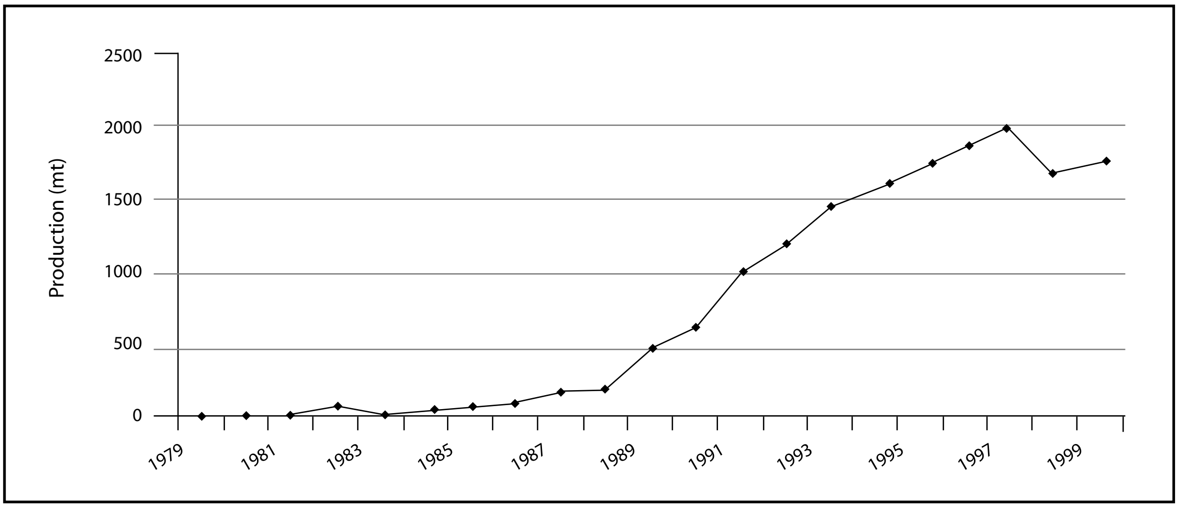

Figure 1. Aquaculture production from introduced tilapia in Africa.

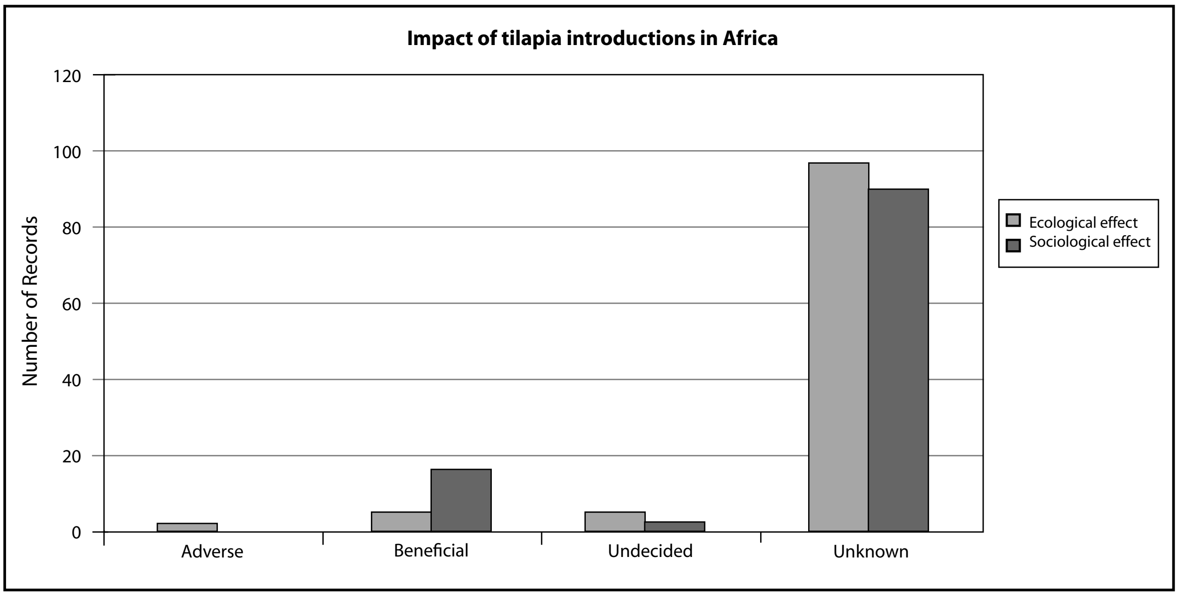

Figure 2. Impact of tilapia introductions in Africa (from DIAS).

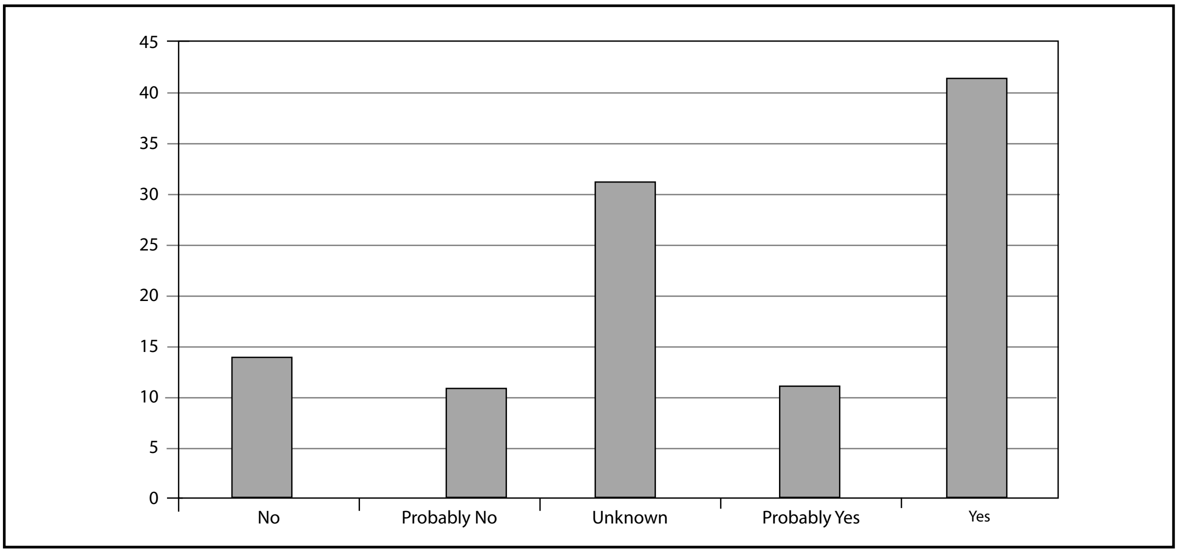

Figure 3. Number of records indicating whether or not tilapia introduced into Africa established self-sustaining populations.

genetics, disease and habitat modification. Economic risk from using alien species or genotypes includes failed breeding programs, poor production and failure to be able to respond to market demands.

When considering the special case of tilapia re-introduced to Africa, species interactions and genetic concerns figure most prominently. Most tilapias appear to be able to form viable inter-specific hybrids (Macaranas et al. 1986; Agnèse et al. 1998; Bartley 2001) and thus on escaping from culture could breed with local species. Agnèse et al. (1998) pointed out the difficulties in predicting the outcome of various ecological interactions between different tilapia species: in one example one species would emerge as dominant after a period of hybridization, whereas in another area the interaction would result in the reverse outcome. Thus, transgenes inserted into one species of tilapia would then have a means to move into other related tilapia species. This could have minimal or maximal impact depending on the phenotypic change imparted by the trans-gene in its new host in the new environment.

With the vast array of genetic technologies available, in analyzing risk it will be more important to focus on the phenotypic change these technologies produce than on the technologies themselves. A diverse international group of experts stated that policies concerning the use of genetic technologies must, "Recognize that in the formulation of biosafety policy and regulations for living modified organisms, the characteristics of the organisms and of potentially accessible environments are more important considerations than the processes used to produce those organisms," (Pullin et al. 2000).

Disease concerns are discussed in detail by Subasinghe (this volume). We do have good information on tilapia pathogens and disease is not a major hindrance to tilapia culture. However, looking at experiences from other species, there are examples where conspecifics moved outside their range or re-introduced back into their range have caused unexpected disease problems. Atlantic salmon moved from the Baltic Sea to Norway infected Norwegian Atlantic salmon with a parasite to which Norwegian salmon had no resistance. European cupped oysters that were re-introduced to Europe from the Pacific Northwest of North America carried the pathogen bonamia with it that has caused the collapse of the European cupped oyster industry.

Tilapia has been domesticated in Southeast Asia, primarily in the Philippines and it is expected that although disease resistance was not specifically selected, it did come along with the domestication process (Tave 1996). Thus, tilapia genetically improved outside of Africa may be resistant to numerous pathogens to which the unimproved or native tilapia would be susceptible (they may have pathogens that could effect other fish species as well, not only tilapia). The genetically improved tilapia may act as carriers for these pathogens and could serve as a mechanism to transmit disease to native African fish.

We have a variety of information to incorporate into our risk analysis. However, as knowledgeable scientists we know we will never have enough information to address completely the complexities of moving new species and genes into areas being used by humans. Therefore, we must also insert an element of precaution, that is, how to proceed with limited or incomplete knowledge. FAO and the Government of Sweden produced guidelines and reviews on the precautionary approach to capture fisheries and species introductions (Bartley and Minchin 1997; FA0 1997). Elements of the precautionary approach are outlined in Table 1. This approach does not equate to a ban on species introductions, although by the "reversibility" criterion, alien species are not precautionary. Nor does the approach serve as an excuse not to reduce uncertainty. The establishment of reference points will require scientific rigor and the collection and monitoring of various types of data.

Realizing that we must take special precautions to protect aquatic diversity because of limited knowledge may be considered a type of wisdom, which is the subject of the next section.

Wisdom

We now move to the most difficult of our steps. If we collect information and organize it into knowledge, then surely wisdom will follow. Hopefully it will, but it is not a certainty. Wisdom has been defined as "soundness of judgement". And here lies a problem: judgement of one may not be the same as others because of different personal, cultural, and economic backgrounds. It also may be different because of the ways we organize our information and how we deal with uncertainty.

There are a few common goals in regard to sound judgement, such as long-term sustainability, equity, and peace. However, these are not independent of a society's or decision-maker's

Table 1. Elements of a precautionary approach to the use of alien species/genotypes.

Element	Example
Establishment of reference points	Less than 0.1 per cent escape from fish farm
Establish pre-agreed actions and contingency plans as reference points are reached	Improve containment of farm; relocate farm; close farm
Maintain productive capacity of resource	Conserve local diversity in African tilapias
Impacts should be reversible within 20 to 30 years	Difficult to reverse an introduction that has caused environmental problems. Mitigation could be part of pre-agreed actions
Burden and standard of proof	Controversial: who should bear this burden?

background, and achieving them will also require strong political will. Providing for rural populations, conservation, protecting threatened species are all matters to be decided, based on political, social, and economic realities in many areas. Short-term gains from using alien species must be balanced against the long-term threats to natural ecosystems. Can well thought-out, planned, and monitored introductions have long-term gains?

Perhaps the "wisest" thing to do is to follow a precautionary approach (above), and first reflect on the necessity of the importation of exotic species, or even individual fish. If a local alternative exists, why run all these, mostly irreversible, risks of importing individuals or exotic species? An example could be the development of a Genetically Improved Farmed Tilapia for use by farmers in developing countries, based on local populations, by the WorldFish Center (2001). Only if the use of local alternatives is not feasible, the introduction of an exotic species could be considered, using the different codes and guidelines concerning species introduction, such as those developed by the International Council for the Exploration of the Sea (ICES) (1995) that have been adopted in principle by FAO regional bodies and have been incorporated into the FAO Code of Conduct for Responsible Fisheries (ftp://ftp.fao.org/docrep/fao/003/W3592e/W3592e00.pdf). The basic elements of these codes require that:

- a proposal to introduce an alien species must be submitted to an independent advisory board for review;
- an environmental impact assessment must be done and reviewed;
- the proposal is rejected, accepted or accepted with modification, following the above review;
- neighboring areas and countries that could be impacted are informed;
- monitoring and quarantine measures are established; and
- the program should be modified as necessary, based on monitoring and evaluation.

In the case of tilapia in Africa, non-introgressed native populations, i.e., those that have not interbred with alien species, are getting harder and harder to find; the domestication process including genetic improvement of native species will create alien genotypes from native genotypes, and the *O.niloticus* has established feral populations in many parts of Africa through its use in aquaculture. It would seem unwise to unduly restrict a developing aquaculture industry from re-importing genetically improved tilapia, or developing breed improvement centers in many parts of Africa where native populations are already introgressed or where the environment has been altered by development. All importation must follow appropriate fish health certification and quarantine procedures.

It would also seem unwise to introduce alien tilapia genotypes into areas where the native tilapia populations are still relatively intact. The genetic diversity of tilapia is extremely complex with different sex determining mechanisms and brooding strategies. This diversity can easily be compromised by alien genotypes. Thus it appears wiser to attempt to zone areas of Africa where alien genotypes would serve aquaculture interests and present minimal threats to the environment. Likewise, there should be zones where alien genotypes are restricted in order to conserve the natural genetic diversity of tilapia. Reference points (for example in Table 2) and monitoring will need to be established to assess the impact and decide on any contingency actions.

Table 2. Some examples of reference points for the application of the precautionary approach to the use of alien species.

Description	Reference Point
Conserve rare genes in wild population	Ne > 100
Acceptable level of gene flow between alien and native species	m < 1
Acceptable level of endangerment for wild population	80, 50, 20 per cent decrease over 10 years or 3 generations
Risk of extinction for wild population	Ne < 50; order of magnitude decreases; 50 per cent probability in 5 years
Presence of pathogens from alien species in wild population	0 tolerance in many cases

The will to establish and enforce such zoning is a crucial and difficult component. Once an alien species or alien genotype has been imported and used in one part of a country, it will be difficult to keep it from spreading to other areas. In this regard, education and awareness-building will also be necessary in order to convince developers that the responsible use of alien species means that in many places, their use will be prohibited.

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Invasive Species in Water-Dependent Ecosystems

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Abstract

Alien invasive species may cause as much havoc in water-dependent ecosystems, such as wetlands, lakes and rivers, as they do in terrestrial systems. In the aquatic medium they are more difficult to detect and eradicate or even to control and there needs to be special effort to avoid such invasions from both alien species and genotypes. This paper describes some of the pathways and impacts of alien and other invasive species in aquatic situations and suggests that the intentional introduction of any species to a new environment should be preceded by a rigorous risk assessment process. The proposed introduction of modified *Oreochromis niloticus* (such as the GIFT strain which is now an alien genotype in Africa) is discussed in this light with examples of the impacts of introductions of this species in other places. It concludes with a plea that risk assessment must be taken extremely seriously for re-introduction in Africa.

Introduction

Alien species are organisms that have been introduced intentionally or accidentally outside of their natural range. Alien invasive species are regarded as the most detrimental to pristine ecosystems and their dependent biodiversity (Williamson 1996; MacNeely 2001). Native species (see below) may also become invasive within their original areas of distribution if ecosystems or habitats change so that the species are "new to their surroundings".

Intentional introductions in aquatic systems are usually brought about through attempts to enhance local fisheries or other food production systems or for the biological control of weeds, other pests or vectors of disease. They can also occur when there are deliberate movements of plants and animals from one country to another when people move or attempt to enhance their surroundings with foreign or familiar biota from other places. Unintentional introductions in rivers, lakes and wetlands come from the escapes of animals or plants from water-based production systems, especially aquaculture in its many forms. Alien species can spread unintentionally through transport and trade as well as travel, tourism and even relief and development aid - the so-called "pathways of invasion" (McNeely et al. 2001; Wittenberg and Cock 2001). The natural spread of invasion occurs once an alien has become established in a new continent, country or ecosystem, especially along river systems and up and down catchments.

Following establishment, there is an unexpected or unnatural expansion of the invading population with harmful effects on the ecosystem that it invades. Invasion may result in domination, competition, exclusion and even extinction of local, natural populations of species, communities, habitats and ecosystems.

The following terms are used in referring to invasions and need some definition:

(i) A native species is a species, subspecies or lower taxon occurring within its natural range and dispersal potential (i.e., within the range it occupies naturally or could occupy without direct or indirect introduction or care by humans).

(ii) An alien species or alien genotype (introduced, non-indigenous, exotic) is a species, subspecies or lower taxon occurring as a result of human agency in an area or ecosystem in which it is not native. A domesticated or genetically altered native species may become an alien genotype.

(iii) An invasive species is a species which colonizes natural or semi-natural ecosystems. It is an agent of change and threatens native biodiversity (species, populations and/or ecosystems).

(iv) An alien invasive species combined (ii) and (iii) above often has the most serious or severe effects because it has not evolved in harmony with the ecosystem, for example it may have no natural "enemies".

The term "water-dependent ecosystems" is used here to refer mainly to streams, rivers, floodplains, wetlands and lakes, but can also include creeks, estuaries and coastal marine systems influenced by freshwater, as well as artificial impoundments (dams, reservoirs, ponds) and constructed wetlands.

Effects of Invasions

Invasive species can be plants or animals or micro-organisms; sometimes they are called weeds or pests or diseases and they cause some changes to ecosystems if they are able to establish themselves. Many introduced species, however, fail to establish or may take decades or centuries to become invasive, but when they do, they mostly cause changes that are deleterious to biodiversity. The main effects of invasions are:

- Competition by invasive plants for light,nutrients, space and niches within a habitat;competition by invasive animals for food, shelter, nesting and resting sites, hunting sites, breeding sites and places for cover from predators;

- Growth inhibition by invasive plants of other (native) plants through root exudates and other means;

- Physical dominance and cover of plants by invasive herbs, shrubs, trees, creepers and fast-growing climbers;

- Predation of animals by invasive animal species; infection by invading micro-organisms;

- Excessive grazing or browsing of plants by invasive animals;

- Introduction of pests, diseases and pathogens with alien invasive species; and

- Hybridization of aliens with native species and the subsequent reduction or extinction (or permanent alteration) of the native population.

Invasions in water-dependent ecosystems may also have some of the following effects on the water of an ecosystem:

- Alteration (often impediment) of flow and changes in natural cycles of flow;
- Alteration (mostly reduction) of quantity and sometimes also in timing (seasonality);
- Alteration (usually lowering of acceptable standards) of quality in its broadest sense (including eutrophication, de-oxygenation, fouling, poisoning, and reduction of nutrients);
- Reduction or loss of hydrological benefits of wetland function; and
- Alteration of wetland functions downstream of invasions and across national and international borders.

While these are not necessarily the primary effects of the introduction of (say) alien fish, they may become the secondary impacts of such introductions if the fish concerned becomes invasive.

Note: Although the subject of this workshop consultation is the possible introduction of a fish, the effects of invasions relating to plants are just as relevant as there is a significant probability that an invasive herbivore may (directly or indirectly) alter the habitat such that plants become invasive as a result.

Invasions in Water-Dependent Ecosystems

Invasions in lakes, rivers, floodplains, and wetlands are especially problematic because they are difficult to manage. This is because they are hard to detect (especially the submerged species). One reason is because the water they invade is often part of other ecosystems of value. Another reason is because the affected ecosystem or habitat is linked to others through the water sources or drainage systems - both upstream and downstream (Howard 2001; Kasulo 2001).

There are sometimes significant benefits from invasions such as increased fisheries yields from some invasive fish and crustaceans, and the by-products of invasive water-weeds like water hyacinth. Thus it is not possible to provide a prescription for wetland invasive management;

rather it is useful to consider why we want to prevent or control invasions and what is the desired state of an ecosystem after management has succeeded.

Note that in this approach, the impacts of aquatic invasive species are seen primarily as impacts on the invaded ecosystem as well as the possible long-term influences on people's uses of that ecosystem. Water-dependent ecosystems are frequently linked via watersheds, streams, and rivers to downstream systems so it is especially important to consider invasions in the upper catchments of a river basin or lake since these are likely to have the furthest-reaching impact in the long run.

Management of Invasions

The best form of management for invasive species is prevention. This requires that potential pathways for invasions are known and that the identity of potential invasive species can be determined. Both are possible in many cases since the necessary information is becoming widely available through local and global databases of invasive species (for example http://www.issg.org/database) and because experiences are exchanged and lessons learnt are shared around the world. While this is necessary to protect ecosystems from unintentional introductions, there is a more defined process for intentional introductions. It is possible to ascertain if a species proposed for introduction has been shown to be invasive in other situations or at other times and to then make an assessment of the risk that introduction will lead to invasion. This is the process of risk assessment in relation to the proposed introduction of alien species that has its own well-defined logic and procedure (Groves et al. 2001; Wittenberg and Cock 2001). If the assessment shows that the risk is too great, a sensible decision is often to prevent the introduction or to ensure that it does not lead to invasion, if that is possible and feasible. Prevention of introduction of potentially invasive species is widely seen as the best and most effective way to avoid the consequences of invasions by alien and non-alien species. This principle of preventing the introduction of potentially invasive species is fundamental to the strategies for management of invasions as outlined in the Convention on Biodiversity in the Guiding Principles for the Prevention, Introduction and Mitigation of Impacts of Alien Species, by IUCN in the Guidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species and by GISP in the Global Strategy on Invasive Alien Species (McNeely et al. 2001). Codes of practice specific to aquatic species have been developed by the International Council for the Exploration of the Sea (ICES 1995) and have been adopted by the FAO Code of Conduct for Responsible Fisheries (FAO 1995).

If the intentional introduction of a species is proposed but the information for an effective risk assessment is not available, the precautionary approach (Bartley and Minchin 1997; FAO 1996) should be invoked. Thus if there is no certainty that the available information can show that an introduction is not likely to lead to an invasion, the introduction should not go ahead, at least until the information becomes available to make that risk assessment.

Prevention of unintentional introductions is often not possible, so some form of management is required once an invasion has occurred. Ideally the best form of management is eradication - but this is often impossible to achieve - thus we usually refer to control as the process for reducing an invasion to tolerable levels.

Control of invasive in water-dependent ecosystems follows the normal methods for other ecosystems, but does have a special relationship with water due to the associated problems of access, visibility and connection to other ecosystems through the watery environment (Howard 2000):

* Mechanical: Control by removal, destruction, trapping or catching;
* Chemical: Control by pesticides, herbicides and poisons - few of which are specific;
* Biological: Control of exotics and usually with exotic biocontrol agents;
* Ecosystem manipulation: management, such as watershed management, water management, pollution control, competition with crops or local species; and
* Integrated management: strategies using some or all of the above.

Biological control (and associated integrated management) is the most enduring method of management of invasive as it brings original "enemies" (parasites, predators, pathogens, grazers, and browsers) of the invader to reduce its numbers to acceptable levels - just as it was in its native home. Once introduced with the necessary precautions, biological control usually needs little extra inputs and, if properly screened in advance, should have no negative effects on other organisms.

Introduction of Nile tilapia (*Oreochromis niloticus*)

O. niloticus is a freshwater fish native to the Lower Nile River Basin, some lakes of the Albertine Rift Valley, the Lake Chad Basin and some other river systems in West Africa and the Middle East. It has been intentionally introduced into many wild lakes, rivers and wetlands in Eastern and Western Africa to augment local fisheries and has been spread around the tropical and sub-tropical world as a species (or species complex) for aquaculture in Africa, Asia, the Americas and the Pacific. It is a favored and effective species for intensive, extensive, and low intensity production of fish for domestic and market consumption and, as with many other species in pond and cage culture, has a history of escape from the production systems and entry into wild waters wherever it has been cultured. It has become invasive in many situations around the tropics. A few examples are mentioned below.

O. niloticus (in its broadest sense including a range of subspecies, and varieties,) has become invasive in many water and wetland systems as a result of intentional introductions or escapes from aquaculture. Pullin et al. (1997) examined evidence of the impact of introductions of tilapias (especially *O. niloticus*) in Asia and were not convinced of excessive damage done. The invasive nature of *O. niloticus* in Lake Victoria, East Africa, however, is well known and its impacts there have been described as including competition with, and consequent elimination of, other *Orechromis* species, other Cichlidae and possibly other types of fish as well (Pitcher and Hart 1995). Its introduction may have been the final blow that brought about the extinction of *O. esculentus* and *O. variabilis* in much of the lake (Twongo 1995), and it is now recorded as expanding its diet to include invertebrates and other fish as well as zooplankton, algae and plant material. Nevertheless, *O. niloticus* is now a very valuable component of the three-species fishery in Lake Victoria and is a favored food item for local and export consumption.

O. niloticus was introduced to fish farms in Zambia in 1982 from where it escaped to enter the Kafue River, a major tributary of the Zambezi. It was also introduced for aquaculture in the Lake Kariba catchment and has now established in both the middle and lower Zambezi Basins. According to van der Waal (2002), it was distributed further south by anglers and fish farmers and eventually entered the Limpopo River Basin where it has now established and is regarded as a threat, through hybridization, to the indigenous *O. mossambicus.* Hybridization between *O. niloticus* and *O. mossambicus* is known to be possible and has been used to improve fish stocks in aquaculture in many countries. So the threat to the native tilapia of the Limpopo is very real.

O. niloticus and other tilapias are invasive alien species whose introduction in Meso-America is well known. This has happened principally through escapes from aquaculture projects followed by widespread expansion into many waterways, lakes, and even estuaries in several countries including Belize, Costa Rica, Cuba, El Salvador, Honduras, Mexico, and Nicaragua. Notable is the situation in Nicaragua where tilapias have now spread to all of the largest watersheds in the country (McCrary et al. in prep). Several impacts on natural aquatic ecosystems have been documented there. The biomass of native cichlids, once dominant in large sections of Lake Nicaragua, has been reduced by 80 per cent as a result of the establishment of tilapias (McKaye et al. 1995; McKaye et al. 1998). In Lake Apoyo, *O. niloticus* eradicated underwater vegetation (*Chara* sp.) and has occupied or destroyed feeding and breeding niches, and has promoted outbreaks of parasites among native species (McCrary et al. 2001), including species endemic to this lake, thereby presenting special threats of species extinction (McKaye et al. 2002).

These are but a few examples of the invasive potential of *O. niloticus* when it is introduced or escapes into waters where it is not native. Thus the introduction of this species, modified, hybridized, cross-bred or in its original form must be considered as a potential risk in any country. Its introduction in Africa must be preceded by a serious risk assessment, including consideration of the possible risk of invasion and subsequent short and long-term damage to ecosystems upon which many millions of people and diverse biodiversity depend. Short-term gains from enhanced fish species must be balanced with long-term impacts that could threaten or remove sources of survival for people and biodiversity. Introduction to Africa in general should be considered a significant risk and introduction to Eastern Africa, especially where the species is already both native and invasive, an even greater risk from hybridization, expanded invasion and impacts on water-dependent ecosystems and their biodiversity.

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

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Abstract

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

Introduction

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

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

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

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

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

Infrastructure

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

Status of Hatcheries

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

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

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

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

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

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

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

Rearing Facilities

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

Research Institutions

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

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

Feed Availability

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

Human and Administrative Resources

Management and Administration

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

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

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

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

Extension Services

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

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

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

Training in Broodstock Management and Genetic Enhancement

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

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

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

Genetic Enhancement Programs: Planned Fish Breeding

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

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

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

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

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

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

Risk Assessment

Risk of Fish Transfer

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

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

Evaluation Methods

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

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

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

Dissemination of Risk Information

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

Quarantine and Health Management Procedures

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

Legislation

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

Conclusion

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

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

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

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

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Capacity for Conservation of African Aquatic Biodiversity

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Abstract

The status and trend of African biodiversity is reviewed. The major threats facing the aquatic biodiversity in Africa and the conservation efforts to stem the challenges are discussed including the human, institutional, legislative, and policy level capacities. Prior to the introduction of a new germplasm and/or alien species of fish, it is imperative that thorough and comprehensive autecological and synecological studies are undertaken to understand the possible impacts to the ecosystems at large. The paper also observes that gene ecology and gene technology are new concepts with a number of potential risks especially in the African milieu, and recommends that there is a need to develop appropriate regulatory frameworks and to enhance national technological capacities to implement biosafety procedures for the safe application of biotechnology in the fish industry.

Introduction

Life on earth depends on water. Water comprises 99 per cent of the human body and covers 71 per cent of the earth's surface. Too often, however, the life within water is forgotten. The biological diversity of aquatic ecosystems is neglected in developed countries and developing countries alike, even in coral reefs that rival tropical rain forests in extraordinary diversity of life. Over 20 000 species of fish make up more than half of all vertebrate biodiversity; over 8 000 of these live in freshwater. In summary, nearly 25 per cent of the earth's vertebrates live in less than .001 per cent of the earth's water (Shumway 1999). Despite all these facts, the value of aquatic biodiversity in Africa is only beginning to be realized as countries struggle with natural resource management decisions imposed by socio-economic developments, structural adjustment programs, huge debts, and national environment action plans.

Conservation and sustainable use of water and aquatic resources has been a big challenge in Africa, particularly because of the rapid increase in populations in many countries and associated land and catchment degradation (Cumming 1999). The growing realization that water is a finite resource and if not sustainably managed may diminish in quantity and quality and the life within it has led to the development of programs to manage aquatic biodiversity, all of which are affected by a number of factors including the human, institutional, legislative, and policy constraints. The purpose of this paper is to review the status and trends of African biodiversity. Also, the paper seeks to discuss the major threats facing aquatic biodiversity in Africa and the conservation efforts being taken to address these challenges. The measures include the building of capacities in dealing with genetic engineering products and gene technology in general in the development of aquaculture.

In recent years, there has been a growing public and scientific debate on the need for capacity building in the developing countries as an essential pre-requisite for sustainable development. An increasing number of international conventions, organizations, and meetings have addressed exotic species issues and associated management capabilities on a global scale. Some of the major events that provide a policy context are:

- Convention on Biological Diversity (CBD);
- Convention on Wetlands of International Importance especially as waterfowl habitat (Ramsar);
- Cartegena Protocol on Bisafety; and
- Global Biodiversity Assessment prepared by UNEP (which includes a major review of invasive species).

Overview of African Aquatic Biodiversity

Various authors (Roberts 1975; Daget 1984) have described most of the African wetlands.

Table 1. Distribution of fish species by province.

Ichthyofauna province	Species richness	Remarks
Zairean	690	80 per cent endemic
Lower Guinean	340	Area poorly studied
Upper Guinean	>200	Deforestation, dams and exotic species have taken a severe toll on these species
Sudanian	200-300	Rivers in Ethiopia are poorly studied; endemic species found in Danakil depression; three endemics live underground
East Coast	100	Medium levels of endemism; forested mountains in Tanzania and Kenya and coastal rivers of southern Mozambique are known to have higher numbers of endemics, but they are poorly studied
Zambezian	150	Zambezi River supports a number of threatened freshwater fish; *Tilapia guinasana* is a threatened species found in a few sink holes in Namibia
Quanza	110	Endemic cyprinids present in the Lucala River; area poorly studied
Southern (Cape)	33	Contain highly restricted endemics
Maghreb	40	Unknown conservation status

Source: Modified from Shumway 1999.

Hughes and Hughes (1992) in particular, list their major characteristics including fauna, flora, human impact, and utilization. Stiassny (1996) provides the best geographic analyses on the distribution of fish species in Africa and divides the African ichthyofauna into the following provinces (excluding the great lakes): the Zairean province, Lower Guinean province, Upper Guinean province, Sudanian (or Nilo - Sudanian) province, East coast province, Zambezian province, Quanza province, Southern (Cape) province, and Maghreb province. The distribution of fish resources by provinces is summarized in Table 1. Table 2 summarizes freshwater fish species by country.

Threats to African Aquatic Biodiversity

Despite the considerable benefits of freshwater resources to the numerous human populations in Africa, the aquatic biodiversity continues to face mounting threats from human activities. This is especially so, due to the fact that Africa has more semi-arid and desert areas than any other continent, and has a very rapidly increasing human population that exerts pressure on the limited freshwater resources. Threats to the African aquascape are particularly due to a multitude of human-induced stressors such as the introduction of alien species, overuse, the impacts of land use changes in surrounding catchments on the water chemistry, poverty, under-valuation of aquatic resources, and improperly sited aquaculture (Bootsma and Hecky 1993; Lowe-Mconnell 1993). Already, 30 out of 46 commercial fish species in the Nile River are either economically or biologically extinct. Lake Chad has lost 75 per cent of its area in the last 30 years due to water diversion for agriculture and drought (Postel 1995). Table 3 lists African countries with the most threatened fish and amphibian species, from the IUCN Red List of threatened animals (IUCN 1996).

In Lake Victoria, the world has witnessed the largest vertebrate extinction in modern times where the introduction of Nile perch (*Lates niloticus)* has eliminated about 65 per cent of the endemic haplochromine fauna (the cichlids) and caused the loss of about 200 taxa (Goldschmidt et al. 1993; Shumway 1999). Lake Victoria provides an eloquent, if not tragic, example of how a fish fauna, which has taken 750 000 years to evolve, can be decimated within 30 years by the introduction of an alien species. Of all the ecologically damaging factors cited above, the invasion of alien species is considered the second greatest threat to global biodiversity after habitat loss.

Aquatic biodiversity is particularly at risk from introductions of alien species and strains. Alien species of fish have been deliberately introduced into African freshwaters for a number of reasons including fish culture and the need to produce "bigger fish", among other reasons. According to Hamman (1997) 93 aquatic species (70 per cent of which are fish) have been introduced or inappropriately translocated in Southern Africa. In most cases, the economic and biological implications of translocations have not been thought through. For example, we may never know enough to anticipate fully all the risks, particularly the unforeseen and complex interactions of the invading species with the existing food web.

Table 2. Estimated number of freshwater fish species by country in Africa.

Country	Number of freshwater fish species
Algeria	20
Angola	207
Benin	84
Botswana	54
Burkina Faso	99
Burundi	209
Cameroon	342
Central African Rep.	45
Chad	134
Congo	315
Cote d'Ivoire	167
Djibouti	4
Egypt	88
Equatorial Guinea	55
Ethiopia	66
Gabon	169
Gambia, The	93
Ghana	224
Guinea	172
Guinea-Bissau	55
Kenya	255
Lesotho	8
Liberia	115
Libya	9
Madagascar	75
Malawi	361
Mali	123
Mauritania	8
Mauritius	28
Morocco	39
Mozambique	253
Namibia	102
Niger	166
Nigeria	278
Rwanda	42
Senegal	127
Sierra Leone	117
Somalia	35
South Africa	153
Sudan	105
Swaziland	40
Tanzania	682
Togo	60
Tunisia	17
Uganda	291

Table 3. Number of threatened fish and Amphibian species by country.

Country	Threatened fish species	Threatened amphibian species
Uganda	28	0
South Africa	27	9
Cameroon	26	1
Kenya	20	1
Tanzania	19	1
Madagascar	13	1
Seycheles	0	4

Data from the Species Survival Commission (SSC), 1998.

Comparative studies of terrestrial exotic species across taxonomic categories have shown that invading species can affect virtually all ecosystem functions and structural properties, including the alteration of biogeochemical cycling. Studies of aquatic alien species have shown that both predatory and herbivorous species can cause serious ecological damage to endemics, through predation, competition for food or breeding sites, the degradation of habitats and food webs, spreading of diseases and parasites (Leveque et al. 1988). In addition, introduced species can degrade the gene pool, such as hatchery-bred fish, with limited genetic variability, or inter-breed with wild populations. The introductions of alien species in Lakes Victoria, Kyoga and Kivu can provide greater insight on the issue. Despite all these, Africa is still a focus of introductions and there is fairly little attention given to invasive aliens with the exception of water hyacinth and *L.niloticus* in Lake Victoria.

Efforts to Conserve and Sustainably Use Aquatic Biodiversity: the Need for Capacity Building

(i) Conservation Efforts

Efforts to address the many complex and interactive aquatic degradation problems and loss of biodiversity in African countries have a long history. Most countries have established both *in-situ* and *ex-situ* conservation programs. *In-situ* conservation initiatives for biological resources have taken the form of national parks and game reserves. Most of the ecological reserves contain aquatic systems as the most important parts of protected ecosystems. *Ex-situ* conservation programs in Africa have used gene banks and botanical gardens (particularly for aquatic plant genetic resources). In order to ensure effective conservation and development of biodiversity, appropriate institutional frameworks were developed and people trained to man those institutions. The multiple institutions that are concerned with issues of biodiversity management in general and aquatic resources in particular include:

- Line ministries (with their technical departments and divisions) that deal with the sectoral aspects of natural resource conservation such as forestry, water, wildlife, land, fishery, energy, among others;
- Government parastatal institutions (or environmental agencies) – as semi-autonomous institutions are established by acts of parliaments to deliver specific activities such as technical advisory and coordination roles;
- Environmental non-governmental organizations (NGOs) and community-based conservation groups; and
- Institutions of higher learning that contribute considerably to aquatic conservation through research and training.

Along with the creation of new institutions and strengthening the old ones, a wide range of policy and legislative measures have been taken by African countries to promote the conservation and management of biodiversity in general. The policy and legislative interventions have ranged from specific natural resource laws to broad environmental policies and strategic action plans (National Environmental Action Plans- NEAPs). In most African countries the National Environmental Policies (NEP) are holistic and detail an integrated set of sectoral and cross-sectoral policy objectives, institutional structures, and implementation procedures for environmental management.

Despite these measures, the national capacities of African countries to effectively and efficiently manage the aquatic biodiversity have been constrained by a number of factors. These are:

- The sectoral nature of institutions involved in the conservation of biodiversity. The conservation programs are often created along narrow sectoral lines that ignore the ecosystem and the holistic principles necessary for effective resource management;
- Lack of instituted wetland policies and specific laws to promote aquatic conservation;
- Lack of strong institutions and appropriate institutional arrangements to upgrade and implement the existing sectoral policies and legislation;
- Low technological capacities;
- Lack of up-to-date scientific information and data on aquatic ecosystems and species; and
- Lack of financial resources and motivated, well trained human capital.

(ii) Capacity Building

Capacity building is often misinterpreted as merely the building of skills and abilities or provision of financial resources to a society or a community. Capacity building refers to the dynamic process of creating, mobilizing, utilizing, enhancing or upgrading and adjusting the existing capacities of individuals, local communities, institutions and the country-level policy framework in which individuals and institutions grow, operate and interact with their internal and external environments. It is a process whereby a community is equipped to identify and solve problems or perform functions in an effective, efficient and sustainable manner. The process of capacity building must be aimed not only at training, but also at increasing access to resources, changing the power relationships between the parties involved (for example, officials, technicians, local communities) and improving the overall policy, legislative, administrative and institutional contexts.

Many African countries are party to many international conventions and agreements, which have a set of obligations to be fulfilled. The Cartagena protocol on biosafety is even explicit in capacity building. Paragraph 1 of Article 22 provides that "the parties shall cooperate in the development and/or strengthening of human resources and institutional capacities in biosafety, including biotechnology…" and Paragraph 2 (article 22) explicitly states that "For the purposes of implementing paragraph 1 above, in relation to cooperation, the needs of developing country parties…for financial resources and access to and transfer of technology and know-how in accordance with relevant provisions of the Convention shall be taken fully into account for capacity building in biosafety… ".

Article 6 of the Convention on Biological Diversity (UNEP1992) calls each contracting party to "Develop national strategies, plans, or programmes for the conservation of biological diversity…". For this purpose, article 18 explicitly calls for strengthening of technological capabilities in research and conservation in the developing nations through international cooperation. Article 19 of the CBD on handling of biotechnology and distribution of its benefits calls for "each contracting party to take legislative, administrative and policy measures to provide for the effective participation in biological research activities…" and further states that " the parties shall consider the need for and modalities of a protocol setting out appropriate procedures, including, in particular, advanced informed agreement, in the field of safe transfer, handling and use of any living modified organism resulting from biotechnology that may have adverse effect on the conservation and sustainable use of biological diversity".

Conclusion and Recommendations

The aquatic biodiversity in Africa is one of the world's richest treasures. Aquatic ecosystems provide critical services to man and wildlife, to both fauna and flora living on land and in water. However, a critical mass of capacity in such areas as biotechnology, gene ecology, genetic engineering, biosafety, policy analysis, taxonomy, molecular biology, environmental law, and other related technical areas is lacking in the continent. Success in the conservation and management of biodiversity in general, and aquatic biodiversity in particular, will therefore depend on how African countries will organize their institutions, formulate systemic policies and effective legislation, and build the required technological capabilities at local, national and regional levels.

It is, therefore, recommended that in order to effectively manage and develop the aquatic biodiversity, African countries should undertake the following:

- Prior to the introduction of a new germplasm and/or alien species of fish, it is imperative that thorough and comprehensive autecological and synecological studies are undertaken to understand the possible impacts to the ecosystems at large;
- Integrate strategic biodiversity management considerations in science, scientific and technological as well as policy planning to enhance countries' capabilities to generate technologies such as biotechnology and apply them in aquatic biodiversity management;
- Develop capacity in aquatic biodiversity research, planning and policy analysis; and
- Develop institutional reforms to establish new linkages, establish new institutional set ups, create incentives and promote institutional collaboration in specific aquatic biodiversity projects so as to mobilize relevant expertise.

In order to be able to identify and solve problems arising from the conservation and sustainable use of aquatic biodiversity, greater understanding is required on the dynamics and processes of capacity building and greater rigor is imperative in the planning, design and implementation of capacity building activities at all levels.

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Source: Modified from Shumway 1999.

Biodiversity Conservation in Sub-Saharan Africa: Policies, Laws and Institutions to Control/Prevent the Introduction of Alien Invasive Species

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Abstract

The policy and legal instruments as well as institutional arrangements for the regulation and/or control of the introduction of alien species in Sub-Saharan Africa are reviewed. Many countries in Sub-Saharan Africa have integrated measures to regulate the introduction of alien species into their environmental policies and laws as well as in sectoral instruments (for example, fisheries laws, forest laws) and national biodiversity strategies and action plans. The challenge that many of these countries face relates to the accumulation of national capabilities to monitor and scientifically assess impacts of alien species. Review of national policies, laws and agencies that have either implicit or explicit responsibilities and goals of regulating the introduction of alien invasive species into the environment indicate that countries are devoting considerable attention to issues and concerns associated with the introduction and control of alien species. An analysis of the nature of regional instruments and institutions for the control and/or regulation of the introduction of alien species shows that a body of policies and laws, as well as organizational arrangements, have been put in place to handle the trans-boundary introduction of alien species. The need to build national and regional scientific and technical expertise and infrastructure to monitor, assess, and regulate the introduction of alien invasive species, is emphasized.

Introduction

The past three decades have seen considerable concern about the depletion and loss of Africa's biological diversity. Conserving the region's biological diversity has become an important public policy issue at international, regional, and national levels. It is widely recognized that if the remaining biological diversity is left to disappear as a result of overexploitation and other socio-economic activities, the region's prospects of achieving economic recovery and political stability will be eroded. This is because biological diversity, and more specifically, biological resources, is the basis for regional and national economic development, ecological security, and socio-political stability.

Many African countries have formulated policies, enacted laws, and established agencies to conserve biological diversity. These regimes—the policies, laws and agencies—address different components and issues of biological diversity and its management. While some of them focus on ecosystem management as a whole, others are devoted to the regulation of specific activities and conservation of specific components.

This paper focuses on policy and legal instruments as well as institutional arrangements for the regulation and/or control of the introduction of alien species.

National Measures

National environmental plans, policies, and laws as well as seed, quarantine, and agricultural laws of many African countries recognize that alien species may pose problems to the environment in general and to biological diversity in particular. National biodiversity strategies and action plans of several African countries have also identified the need and urgency of implementing Article 8(h) of the Convention on Biological Diversity which states that "each Contracting Party shall, as far as possible and appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species." However, many of the existing measures are implicit are not deliberately instituted to address issues and threats associated with the introduction of alien species (Mugabe et al. 1997).

National Environmental Action Plans (NEAPs) make reference to the importance of regulating the introduction of alien species. Uganda's NEAP devotes attention to issues associated with the introduction of alien species, particularly within and for trans-boundary ecosystems. It commits the National Environment Management Authority (NEMA) to conduct monitoring activities and coordinate the implementation of measures aimed at preventing the introduction of alien invasive species into Uganda's natural environment.

Most countries have national quarantine laws to regulate the importation and prevent the spread of diseases and pests in animals and plants. These laws contain provisions that can be invoked to prevent the introduction of alien invasive species. For example, Mauritius' Plant Act No. 12 of 1976 restricts the importation of any seed and/or plant material without the approval of relevant quarantine authorities. Section 15(2) states that "No person shall plant sugar cane of any variety other than those specified in an Order under subsection (1) except on an experimental scale, with a written authority of the Committee and subject to such conditions as the Committee thinks fit to impose." These provisions of the law can be invoked to control the introduction of alien species of sugar into the country.

Countries have various trade regulations that are implicit instruments for preventing the introduction of alien invasive species. For example, Uganda's agricultural trade and marketing policies stipulate that no person and/or institution shall export and/or import seeds of agricultural crops, for example coffee without a permit from a recognized authority. Customs administration at all borders of the country are required by law to inspect and determine all goods being taken into and out of the country, and to control export and import of seeds without permits.

Measures to regulate the introduction of alien species are also contained in or articulated by fisheries legislation of some of the countries. Kenya's fisheries legislation, The Fisheries Act (Chapter 378 of the laws of Kenya), has implicit provisions on the control of the introduction of alien species. Part II section 5(1) states: "The Director may with the approval of the Minister, by notice in the Gazette, impose.….the following measures that are necessary for the proper management of any fishery.….control of the introduction into, or harvesting or removal from any Kenya fishery waters of any aquatic plant." Some national fisheries laws tend to contain explicit provisions to regulate the introduction of alien species. Malawi's Fisheries Act No. 25 of 1997 has explicit reference to the introduction of alien species. Part XI section 41(1) c provides that, "No person shall, without a permit granted by the Director introduce into any water any fish not indigenous thereto."

A few African countries have taken deliberate steps to revise their environmental policies and laws to integrate provisions of Article 8(h) and other articles of the Convention on Biological Diversity. These countries include Gambia and the Seychelles. The Seychelles's Biological Diversity and Conservation Areas Act is a consolidation of various sectoral laws. It outlines fundamental principles and policies to conserve and sustainably use the country's biological diversity. The law establishes the Coastal and Marine Biodiversity Authority whose functions include monitoring and ensuring the prevention of the introduction of alien invasive species that may threaten coastal and marine ecosystems. Article 53 of the law provides explicit measures to prevent the introduction of alien invasive species.

The Gambian National Environment Management Act of 1994 has explicit measures to prevent the introduction of alien invasive species. It creates a Council that is mandated to develop specific guidelines and regulations on the prevention of the introduction of alien species. The Council has, however, not yet taken up this responsibility to institute guidelines and regulations on alien invasive species.

There are a variety of institutions responsible for issues or matters pertaining to the prevention of the introduction of alien invasive species. These include ministries/departments of agriculture, environment,trade, fisheries, immigration and national security. In many countries of Africa, the challenges are not about the establishment of new agencies to deal with matters of alien invasive species, but those of how to ensure synergy between and coordination of various sectoral institutions. In many countries, sectoral agencies do not communicate, share information, and coordinate their activities. This has often resulted in poor or bad decision making.

Some of the African countries have started making major investments in the development of risk management instruments that include policies, regulations, guidelines, and laws. These instruments (commonly referred to as biosafety frameworks) are being established to address, regulate and manage risks associated with the introduction of living modified organisms (LMOs). Kenya's biosafety guidelines are founded on the desire "to benefit from the development and use of modern biotechnology given that none of the existing regulations and acts are geared towards addressing specifically biosafety in the development and use of biotechnology products" (National Council for Science and Technology 1998). The proposed framework describes national biotechnology R&D efforts and states that risk assessment and management regimes should aim at promoting these efforts in such ways as to ensure that they generate products and processes that are safe for the environment and human health.

Zambia's draft bill on biosafety is largely regulatory. It places emphasis on the creation of an institutional framework to regulate the application of modern biotechnology through inspection of R&D facilities and restriction of importation of Living Modified Organisms (LMOs). For example, Part V section 14.1 states that "users shall ensure that all appropriate measures are taken to avoid adverse impacts to the environment and human health, which might arise from the use of genetically modified organisms." Section 14.2 requires users "to carry out a prior assessment of the uses as regards the risk to the environment in accordance with protocols approved by the Board."

Mauritius biosafety framework focuses on measures for the safe development and introduction of genetically modified organisms. For example, the country applied modern biotechnology to generate herbicide-resistant traits in sugar cane. The framework articulates the country's aspiration to extend the application of the technology to other sectors such as aquaculture. The framework largely recommends practices and procedures for the safe use of modern biotechnology in Mauritius.

Regional Instruments and Institutions

Invasive species do not recognize geopolitical boundaries and thus regional and sub-regional cooperation is vital for the effective regulation and/or control. Such cooperation is required between and within countries. It needs the participation of various national and regional agencies, as well as the commitment of politicians, scientists and policymakers across sectors. It is about the involvement and cooperation of ministries of wildlife, environment, trade, agriculture, and education. The regulation and control of the introduction of alien invasive species also require synergies between conventions on trade, agriculture, and environment.

There are a number of sub-regional and regional instruments that can be used to regulate and/or control the introduction and use of alien species in Africa. These are mainly conventions dealing with the environment, agriculture, and trade. The Treaty for the Establishment of the East African Community, the Southern Africa Development Community Treaty, and the treaty establishing the Common Market for Eastern and Southern Africa (COMESA) provide measures to regulate and/or control the introduction of alien species, particularly invasive ones. In Article 8 of the Memorandum of Understanding between the partner states of the East African Community (EAC), Partner States agree to "regulate, control and, where necessary, prohibit the introduction of alien genetic materials including exotic species of flora and fauna" in Lake Victoria.

African countries have adopted regional environmental treaties that set out regional and national action plans to implement agreed goals, including the control or regulation of the introduction of alien species. One of the earliest regional treaties was the 1900 London Convention for the Protection of Wild Animals, Birds and Fish in Africa that was adopted by Great Britain, Italy, Portugal, Spain, and France. The aim of the treaty was to "prevent the uncontrollable massacre and to ensure the conservation of diverse wild species in their African possessions" which are useful to man or inoffensive (cited in Sands 1995). This treaty was replaced in 1933 by the London Convention Relative to the Preservation of Flora and Fauna in their Natural State. These early treaties provided measures to control the movement and introduction of alien invasive species of flora and fauna. The London Convention was replaced by the African Convention on the Conservation of Nature and Natural Resources negotiated under the auspices of the Organization of African Unity (OAU) and adopted in Algiers in 1968. The Algiers Convention aims to "ensure conservation, utilization and development of soil, water, flora and faunal resources in accordance with the scientific principles and with due regard to the best interests of the people (cited in Sands 1995). This treaty has explicit provisions on the introduction of alien species.

Other regional treaties that can be invoked to regulate the introduction of alien species and control threats of such species on ecosystems include the 1985 Protocol Concerning Protected Areas and Wild Fauna and Flora in the Eastern African Region adopted as a protocol to the 1985 Nairobi Convention for the Protection, Management and Development of Marine and Coastal Environment of the Eastern African Region. The protocol commits its parties to "take all appropriate measures to maintain essential ecological processes and life support systems, to preserve genetic diversity, and to ensure the sustainable utilization of harvested natural resources under their jurisdiction (cited in Sands 1995). The protocol provides for meetings of the parties to review the implementation of the protocol, assess the need for further measures and adopt or amend annexes.

The Lusaka Agreement entered into in 1996 aims at controlling illegal trade in endangered species. It has six members. One of its attributes is that it empowers authorities to monitor and regulate the introduction of alien species that may pose a threat to fauna. Other regional agreements, such as the one establishing the Lake Victoria Fisheries Organization, have provisions on the regulation and/or control of alien species. The effectiveness of these treaties as instruments for regulating the introduction of alien species has been hampered by inadequate policy frameworks for implementation, constraints on financial resources, lack of qualified personnel, and poor knowledge or lack of awareness of the content of the agreements (UNEP 1999).

Capacity Building Considerations

While most African countries have created institutions to deal with issues of alien invasive species, these institutions are poorly funded, coordinated and organized to engage in the activities and process of monitoring, conducting scientific studies and regulating the introduction of alien invasive species.

Most African countries have not established programs that are deliberately aimed at studying and assessing problems associated with alien invasive species. Where some research is conducted, it is often an add-on to other activities whose goals are not necessarily about the prevention of introduction of alien species. Thus many of the countries have tended to make decisions on the basis of very scanty, and in many cases, no scientific knowledge and information.

Article 15(1) of the Cartagena Protocol on Biosafety requires that risk assessments "undertaken pursuant to this Protocol shall be carried out in a scientifically sound manner, …taking into account recognized risk assessment techniques…". Paragraph 2 requires that the "Party of import shall ensure that risk assessments are carried out for decisions taken under Article 10". This means that even in the absence of scientific knowledge and information on the LMO and its potential impacts on biological diversity and human health, countries importing must either undertake risk assessments by themselves or require that the exporter undertakes the assessment. Key questions that arise in the case where the exporter's risk assessments are the only ones that form the basis for the importer's decision making are: (i) how transparent and rigorous are the exporter's assessment to inform the importer's decisions given that the exporter has or may have a commercial interest to export? (ii) what technological opportunity costs is the importer foregoing by not undertaking the assessments? and (iii) in case where the importer allows importation on the basis of the exporter's assessment, how will redress and liability be handled if and when the imported LMOs cause environmental and human health risks in the importing countries?

The effectiveness of existing policies, laws and agencies lies in the capacity of countries to engage in scientific analysis of the nature of LMOs and related biotechnology processes. The monitoring and assessment of impacts of alien species will require scientific infrastructure and other capacity components that are absent in many African countries. Few countries have the necessary scientific and technical capacity to engage in risk assessment. Those countries that are building capacity in biotechnology R&D also possess risk assessment infrastructure. It is not the mere formulation and adoption of policies, guidelines and laws that constitute national competency to handle risks from LMOs. Countries will require expertise in a variety of scientific areas, for example biochemistry, molecular genetics, biochemical engineering, and plant breeding to successfully assess and manage risks, even to prevent the introduction of alien species. In many countries where this expertise exists, it is locked away in isolated agencies, many of which may not be engaged in research on alien species. Many of the countries lack the necessary institutional arrangements to mobilize the scientists and direct their skills towards the assessment of risks, leave alone towards the development and application of biotechnology. Indeed, where existing expertise does reside in the institution that is charged with the respective responsibilities of R&D, it is often not drawn upon and utilized. Addressing this problem will require institutional reforms that enlarge administrative space and organizational outreach to recognize, mobilize, and utilize the expertise.

The effectiveness of national efforts to implement provisions of Article 8(h) and the Protocol will largely depend on the nature (including clarity) of institutional arrangements and regulations that countries will establish. It is crucial that African countries carefully determine the most appropriate institutional arrangement(s) for handling matters associated with it. Because of the costs associated with the creation and sustaining several institutions, the countries may wish to consider designating a single competent agency to handle all matters associated with the introduction of alien invasive species. Countries may wish to designate focal points or coordinating agencies. Such focal points will monitor and conduct assessments or mobilize expertise for doing so.

Some of the countries (for example Mauritius and Namibia) have already designated national biosafety focal points to handle biosafety issues. Others such as Kenya have not yet adopted a clear institutional arrangement. The countries will now need to review their institutional options in light of the Protocol and establish or designate institutions. These arrangements should have explicit responsibilities of handling issues and problems of alien invasive species.

In addition to the institutional issues, the countries will require explicit regulations and strategies. The regulations and strategies that would enable the countries to effectively prevent the introduction of alien invasive species are those that:

(i) Focus on the development of national scientific and technological competence in relevant fields of monitoring, assessment and analysis;
(ii) Contain as much clarity as possible on such issues as liability and redress; and
(iii) Build upon such existing measures as those related to food and drugs importation and quarantine.

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The Role of the Convention on Biological Diversity and the Cartagena Protocol on Biosafety in Minimizing Adverse Effects of Invasive Alien Species and Living Modified Organisms[1]

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Abstract

This paper describes the Convention on Biological Diversity and the Biosafety Protocol and their role in relation to minimizing the adverse effects of alien species and living modified organisms (LMOs).

The introduction of alien species into ecosystems has the potential to adversely affect biological diversity. The Convention on Biological Diversity (CBD), an international agreement with 182 member countries including 53 in Africa, requires parties to prevent the introduction of, control or eradicate those alien species that threaten ecosystems, habitats or species. The parties to the Convention have developed guiding principles for the prevention, introduction, and mitigation of impacts of alien species, which are an important guide for managing species introductions. The Convention also addresses the more specific issue of biosafety, referring to the need to protect the environment and human health from the possible adverse effects of organisms that are modified using techniques of modern biotechnology. The parties to the Convention developed and adopted an agreement on biosafety, known as the Cartagena Protocol on Biosafety, aimed at ensuring an adequate level of protection in the safe transfer, handling and use of living modified organisms (LMOs) resulting from modern biotechnology.

Some key provisions of the Protocol include requirements for: (i) an advance informed agreement regarding the trans-boundary movement of LMOs intended for introduction into the environment; (ii) risk assessment and risk management; (iii) handling, transport, packaging, and identification of LMOs; (iv) capacity building; and (v) information sharing. Significant progress has been made towards operationalizing a number of these provisions, particularly those with procedural requirements, in preparation for entry into force of the Protocol.

The Convention on Biological Diversity

The world's biological diversity provides humanity with an abundance of goods and produce, including food, energy, and fibers. It is also the foundation for natural processes that help control soil erosion, purify water and air, and recycle carbon and nutrients. Furthermore, the genetic resources associated with biological diversity are useful in the development of pesticides, vaccines, more productive strains of crops and fish, and other resources. They are also the cornerstones of biotechnology development.

It has been understood for decades that many human activities affect the distribution and abundance of species and, therefore, impact biological diversity. Numerous initiatives in the 1970s and 1980s aimed to stem the loss of species and ecosystems. A consensus gradually emerged, however, that the Earth's genetic resources could be conserved and sustainably used only through international cooperation and funding, based on the introduction

[1] The views presented in this paper do not necessarily represent the views of the Secretariat of Convention on Biological Diversity.

of a suitable international legally binding instrument.

As a result, the Convention on Biological Diversity, negotiated under the auspices of the United Nations Environment Programme (UNEP), was adopted in 1992 and entered into force in 1993. Its aims are the conservation of biological diversity, the sustainable use of biological resources, and the fair and equitable sharing of benefits arising from the use of genetic resources.

Alien Species under the Convention

The Convention on Biological Diversity states in Article 8(h) that "each Contracting Party shall, as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species."

Given this mandate, the Convention's member governments who together constitute the Conference of the Parties (COP) to the Convention made numerous decisions with respect to alien species, many of which are directly relevant to the management of alien species. Most importantly, the COP, at its sixth meeting in April 2002, adopted a set of guiding principles on the introduction of alien species. These guiding principles include definitions of alien species and invasive alien species (Annex 1).

At least two publications by the CBD are of direct relevance to the assessment of impacts from alien species. First, a publication on the assessment and management of alien species (SCBD 2001a) resulted from the sixth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice in 2001. Second, the CBD Secretariat conducted a review of existing international procedures, criteria and capacity for assessing risk from invasive alien species (SCDB 2001b).

Efforts on the issue of alien species under the Convention are ongoing, including as part of the work programs for marine and coastal biological diversity as well as for inland water biological diversity. Finally, a roster of experts on alien species has been established and this is accessible through the website of the Convention.

Biotechnology and the Need for Biosafety

For thousands of years, people have used various techniques to modify plants and animals to improve food production. One traditional form of genetic manipulation is selective breeding, which makes it possible to promote preferred traits such as improved growth, productivity, nutritional quality, or survival rates for food resources such as fish or crops. Today, selective breeding is being supplemented at a rapid rate by the sophisticated tools of modern biotechnology. Researchers can now take a single gene from a plant or animal cell and insert it into another species to give that species a desired characteristic such as resistance to a destructive pest or disease. The result is commonly referred to as a genetically modified organism (GMO), or as a living modified organism (LMO), resulting from modern biotechnology.

Proponents of this powerful new science argue that biotechnology has the potential, among other things, to boost the production of food resources and reduce annual variability in production due to pests, disease, and other factors. In the case of crops, this could reduce the need to clear more land for farms and for agrochemicals. In the case of fish, increased production could improve food security and reduce the probability of population collapses due to over harvesting. However, some argue that LMOs may pose risks to biological diversity depending on interactions with natural species, or may adversely affect human health.

While advances in biotechnology have great potential for improving human well-being, it is widely recognized that LMOs should be subject to adequate safety measures. Such measures, known collectively as biosafety, seek to ensure the safe transfer, handling, use, and disposal of LMOs.

With the biotechnology industry growing at a rapid rate, the international community agreed on the need to develop a legally binding biosafety protocol under the CBD. Governments recognized that while many countries with biotechnology industries already had national biosafety legislation in place, there was no binding international agreement addressing the movement of LMOs across national borders.

In 1995, the Conference of the Parties (COP) set up an open-ended ad hoc Working Group on Biosafety to draft a protocol. After several years of discussion, the COP adopted the Cartagena Protocol on Biosafety in Montreal on 29 January 2000. The Protocol is named to honor the city of Cartagena, Colombia, which had hosted the COP's first extraordinary meeting intended to finalize and adopt the Protocol in 1999.

The Biosafety Protocol

The Biosafety Protocol is intended to provide an international regulatory framework for the growing biotechnology industry that will reconcile the interests of international trade and the need for environmental protection. Its aim is to *"contribute to ensuring an adequate level of protection in the field of the safe transfer, handling and use of LMOs resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health, and specifically focusing on trans-boundary movements."* The Protocol will promote the environmentally sound application of biotechnology, making it possible to benefit from biotechnology's potential, while minimizing the risks to the environment and human health. It will also make it easier for governments, businesses, and civil society to collaborate with one another on strengthening biosafety.

The Protocol offers a number of tools for promoting biosafety:

- *Advance Informed Agreement procedure (AIA)*: The Protocol sets out an advance informed agreement procedure that must be followed prior to the first shipment of an LMO intended for introduction into the environment (such as seeds or live fish). In these cases, the exporter must provide a detailed, written description of the organism to the importing country in advance of the shipment. The importer is to acknowledge receipt of this information within 90 days and then explicitly authorize the shipment within 270 days or state its reasons for rejecting the LMO. (Note: the absence of a response, however, is not to be interpreted as implying consent.)

  The purpose of the AIA procedure is to ensure that recipient countries have both the opportunity and the capacity to assess risks that may be associated with an LMO before agreeing to its import. It should be stressed that the procedure applies only to the first trans-boundary movement of an LMO intended for introduction into the environment. It does not apply to LMOs in transit through a country, LMOs destined for contained use (in a scientific laboratory for example), or LMOs to be directly used as food or animal feed or for processing (such as corn or tomatoes).

- *Risk assessment and risk management framework:* Governments will decide whether or not to authorize the importation of LMOs after assessing the associated risks. These assessments are to be undertaken in a scientific manner based on recognized risk assessment techniques, in accordance with the guidance provided in Annex III of the Protocol. In accordance with the precautionary principle, lack of scientific certainty does not prevent governments from making decisions in order to avoid potential adverse effects.

  In addition, the Protocol requires governments to establish and maintain mechanisms, measures, and strategies for regulating, managing, and controlling risks identified in the risk assessment procedures.

  The Protocol also recognizes the right of importing countries, in reaching a decision on import, to take into account socio-economic considerations such as the value of biological diversity to their indigenous and local communities, provided it is consistent with their international obligations.

- *Handling, transport, packaging and identification:* The Protocol provides for development of standards for the handling, transport, packaging, and identification of LMOs that are subject to intentional trans-boundary movement. Regarding documentation, LMOs that are intended for introduction into the environment must be clearly identified as LMOs, and documentation must specify the identity and relevant traits and/or characteristics, any requirements for the safe handling, storage, transport and use, the contact point for further information, and the name and address of the importer and exporter.

- *Capacity building:* The Protocol promotes international cooperation to help developing countries and countries with economies in transition build the appropriate human resources and institutional capacities. It also encourages governments to assist with scientific and technical training and to promote the transfer of technology, know-how, and financial resources. Because the Protocol is part of the Convention on Biological Diversity, biosafety activities will be eligible for support from the Convention's "financial mechanism". Governments are also expected to facilitate private sector involvement in capacity building.

  One aspect of capacity building for implementation of the Protocol has been the formation of a roster of experts. Governments have been invited to nominate experts who are specialized in fields relevant to implementation of the Protocol. The roster of experts will ultimately be a valuable resource for assisting governments in assessing risks and benefits of LMOs.

- *Biosafety Clearing-House:* The Protocol establishes a Biosafety Clearing-House to facilitate the exchange of scientific, technical, environmental and legal information on living modified organisms. The Clearing-House will also include information on national laws and regulations applying to LMOs not covered by the AIA procedure, namely, agricultural commodities to be directly used as food, feed, or for processing, and LMOs in transit or contained use. This information will be vital for enabling governments to implement the Protocol.

- *Public awareness:* While the Protocol concentrates on international action, it recognizes that national measures are essential to making its procedures effective. Member governments, therefore, commit themselves to promoting public awareness, ensuring public access to information, and consulting the public in decisions about biosafety. They must also take national measures to prevent illegal shipments and accidental releases of LMOs, and they must notify affected or potentially affected states in the event that anunintentional trans-boundary movement occurs.

Current Status of the Protocol

Only after 50 governments have ratified (or acceded to) the Protocol, will the agreement enter into force and become legally binding on its members. More than 100 governments signed the Protocol indicating their intent to ratify it. However, the process of ratification takes varying degrees of time within each country, and as of mid-March 2002, only 13 countries had ratified. Once there are 50 ratifications, a decision-making body called the Meeting of the Parties to the Protocol (MOP) will manage the Protocol's development and implementation. Annex 2 and 3 list the African countries that are Parties to the Convention, signatories to the Protocol, and Parties to the Protocol as of 26 March 2002.

Until entry into force, governments will continue to discuss biosafety and the Protocol within an Intergovernmental Committee for the Cartagena Protocol on Biosafety (ICCP). The ICCP has been mandated by the Conference of the Parties (COP) to prepare for the first Meeting of the Parties to the Protocol, at which time the ICCP will cease to exist.

The first meeting of the ICCP was held in December 2000 and was attended by 578 participants from 82 governments and 133 United Nations bodies, inter-governmental, non-governmental and industry organizations. The meeting considered issues that had been identified by COP 5, namely: information sharing and the Biosafety Clearing-House; capacity building; decision-making procedures; handling, transport, packaging and identification; and compliance. The conclusions and recommendations of the meeting are contained in its report (document UNEP/CBD/ICCP/1/9) available on the website of the Secretariat.

The second meeting of the ICCP held in October 2001 discussed additional issues concerning liability and redress, monitoring and reporting, the Secretariat, guidance to the financial mechanism, rules of procedure for the meeting of the parties, consideration of other issues necessary for effective implementation of the Protocol, and elaboration of a draft provisional agenda for the first meeting of the parties.

Following recommendations of ICCP-1 and ICCP-2, many steps have been taken towards the implementation of the Protocol including the development of a pilot phase of the Biosafety Clearing House, development of a roster of experts, development of a database of capacity building initiatives, establishment of links with other organizations involved in biosafety regulation and capacity building, and initial development of documentation requirements for the handling, transport, packaging and identification of alien species.

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Annex 1
Guiding Principle for the Prevention, Introduction and Mitigation of Impacts of Alien Species

Introduction

This document provides all governments and organizations with guidance for developing effective strategies to minimize the spread and impact of invasive alien species. While each country faces unique challenges and will need to develop context-specific solutions, the Guiding Principles give governments clear direction and a set of goals to aim toward. The extent to which these Guiding Principles can be implemented ultimately depends on available resources. Their purpose is to assist governments to combat invasive alien species as an integral component of conservation and economic development. Because these 15 principles are non-binding, they can be more readily amended and expanded through the Convention on Biological Diversity's processes as we learn more about this problem and its effective solutions.

According to Article 3 of the Convention on Biological Diversity, States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.

The terms as defined in the footnote are used in the Guiding Principles below. Also, while applying these Guiding Principles, due consideration must be given to the fact that ecosystems are dynamic over time and so the natural distribution of species might vary without involvement of a human agent.

A.General

Guiding principle 1: Precautionary approach

Given the unpredictability of the pathways and impacts on biological diversity of invasive alien species, efforts to identify and prevent unintentional introductions as well as decisions concerning intentional introductions should be based on the precautionary approach, in particular with reference to risk analysis, in accordance with the guiding principles below. The Precautionary Approach is that set forth in principle 15 of the 1992 Rio Declaration on Environment and Development and in the preamble of the Convention on Biological Diversity. The precautionary approach should also be applied when considering eradication, containment and control measures in relation to alien species that have become established. Lack of scientific certainty about the various implications of an invasion should not be used as a reason for postponing or failing to take appropriate eradication, containment and control measures.

Guiding principle 2: Three-stage hierarchical approach

1. Prevention is generally far more cost effective and environmentally desirable than measures taken following introduction and establishment of an invasive alien species.

2. Priority should be given to preventing the introduction of invasive alien species, between and within States. If an invasive alien species has been introduced, early detection and rapid action are crucial to prevent its establishment. The preferred response is often to eradicate the organisms as soon as possible (principle 13). In the event that eradication is not feasible or resources are not available for its eradication, containment (principle 14) and long-term control measures (principle 15) should be implemented. Any examination of benefits and costs (environmental, economic and social) should be done on a long-term basis.

Guiding principle 3: Ecosystem approach

Measures to deal with invasive alien species should, as appropriate, be based on the ecosystem approach, as described in decision V/6 of the Conference of the Parties.

Guiding principle 4: The role of States

1. In the context of invasive alien species, States should recognize the risk that activities within their jurisdiction or control may pose to other States as a potential source of invasive alien species, and should take appropriate individual and cooperative actions to minimize that risk, including the provision

of any available information on invasive behaviour or invasive potential of a species.

2. Examples of such activities include:
   (a) the intentional transfer of an invasive alien species to another State (even if it is harmless in the State of origin); and
   (b) the intentional introduction of an alien species into their own State if there is a risk of that species subsequently spreading (with or without a human vector) into another State and becoming invasive;
   (c) activities that may lead to unintentional introductions, even where the introduced species is harmless in the state of origin.

3. To help States minimize the spread and impact of invasive alien species, States should identify, as far as possible, species that could become invasive and make such information available to other States.

Guiding principle 5: Research and monitoring

In order to develop an adequate knowledge base to address the problem, it is important that States undertake research on and monitoring of invasive alien species, as appropriate. These efforts should attempt to include a baseline taxonomic study of biodiversity. In addition to these data, monitoring is the key to early detection of new invasive alien species. Monitoring should include both targeted and general surveys, and benefit from the involvement of other sectors, including indigenous and local communities. Research on an invasive alien species should include a thorough identification of the invasive species and should document: (a) the history and ecology of invasion (origin, pathways and time-period); (b) the biological characteristics of the invasive alien species; and (c) the associated impacts at the ecosystem, species and genetic level and also social and economic impacts, and how they change over time.

Guiding principle 6: Education and public awareness

Raising the public's awareness of the invasive alien species is crucial to the successful management of invasive alien species. Therefore, it is important that States should promote education and public awareness of the causes of invasion and the risks associated with the introduction of alien species. When mitigation measures are required, education and public-awareness-oriented programmes should be set in motion so as to engage indigenous and local communities and appropriate sector groups in support of such measures.

B. Prevention

Guiding principle 7: Border control and quarantine measures

1. States should implement border controls and quarantine measures for alien species that are or could become invasive to ensure that:
   (a) intentional introductions of alien species are subject to appropriate authorization (principle 10);
   (b) unintentional or unauthorized introductions of alien species are minimized.

2. States should consider putting in place appropriate measures to control introductions of invasive alien species within the State according to national legislation and policies where they exist.

3. These measures should be based on a risk analysis of the threats posed by alien species and their potential pathways of entry. Existing appropriate governmental agencies or authorities should be strengthened and broadened as necessary, and staff should be properly trained to implement these measures. Early detection systems and regional and international coordination are essential to prevention.

Guiding principle 8: Exchange of information

1. States should assist in the development of an inventory and synthesis of relevant databases, including taxonomic and specimen databases, and the development of information systems and an interoperable distributed network of databases for compilation and dissemination of information on alien species for use in the context of any prevention, introduction, monitoring and mitigation activities. This information should include incident lists, potential threats to neighbouring countries, information on taxonomy, ecology and genetics of invasive alien species and on control methods, whenever available. The wide dissemination of this information, as well as national, regional and international guidelines, procedures and recommendations

such as those being compiled by the Global Invasive Species Programme should also be facilitated through, *inter alia*, the clearing-house mechanism of the Convention on Biological Diversity.

2. The States should provide all relevant information on their specific import requirements for alien species, in particular those that have already been identified as invasive, and make this information available to other States.

Guiding principle 9: Cooperation, including capacity building

Depending on the situation, a State's response might be purely internal (within the country), or may require a cooperative effort between two or more countries. Such efforts may include:

(a) programmes developed to share information on invasive alien species, their potential uneasiness and invasion pathways, with a particular emphasis on cooperation among neighboring countries, between trading partners, and among countries with similar ecosystems and histories of invasion. Particular attention should be paid where trading partners have similar environments;

(b) agreements between countries, on a bilateral or multilateral basis, should be developed and used to regulate trade in certain alien species, with a focus on particularly damaging invasive species;

(c) support for capacity-building programmes for States that lack the expertise and resources, including financial, to assess and reduce the risks and to mitigate the effects when introduction and establishment of alien species has taken place. Such capacity building may involve technology transfer and the development of training programmes;

(d) cooperative research efforts and funding efforts toward the identification, prevention, early detection, monitoring and control of invasive alien species.

C. Introduction of species

Guiding principle 10: Intentional introduction

1. No first-time intentional introduction or subsequent introductions of an alien species already invasive or potentially invasive within a country should take place without prior authorization from a competent authority of the recipient State(s). An appropriate risk analysis, which may include an environmental impact assessment, should be carried out as part of the evaluation process before coming to a decision on whether or not to authorize a proposed introduction to the country or to new ecological regions within a country. States should make all efforts to permit only those species that are unlikely to threaten biological diversity. The burden of proof that a proposed introduction is unlikely to threaten biological diversity should be with the proposer of the introduction or be assigned as appropriate by the recipient State. Authorization of an introduction may, where appropriate, be accompanied by conditions (e.g., preparation of a mitigation plan, monitoring procedures, payment for assessment and management, or containment requirements).

2. Decisions concerning intentional introductions should be based on the precautionary approach, including within a risk analysis framework, set forth in principle 15 of the 1992 Rio Declaration on Environment and Development, and the preamble of the Convention on Biological Diversity. Where there is a threat of reduction or loss of biological diversity, lack of sufficient scientific certainty and knowledge regarding an alien species should not prevent a competent authority from taking a decision with regard to the intentional introduction of such alien species to prevent the spread and adverse impact of invasive alien species.

Guiding principle 11: Unintentional introductions

1. All States should have in place provisions to address unintentional introductions (or intentional introductions that have become established and invasive). These could include statutory and regulatory measures and establishment or strengthening of institutions and agencies with appropriate responsibilities. Operational resources should be sufficient to allow for rapid and effective action.

2. Common pathways leading to unintentional introductions need to be identified and appropriate provisions to minimize such introductions should be in place. Sectoral activities, such as fisheries, agriculture, forestry, horticulture, shipping (including the discharge of ballast waters), ground and air transportation,

construction projects, landscaping, aquaculture including ornamental aquaculture, tourism, the pet industry and game-farming, are often pathways for unintentional introductions. Environmental impact assessment of such activities should address the risk of unintentional introduction of invasive alien species. Wherever appropriate, a risk analysis of the unintentional introduction of invasive alien species should be conducted for these pathways.

D. Mitigation of impacts

Guiding principle 12: Mitigation of impacts

Once the establishment of an invasive alien species has been detected, States, individually and cooperatively, should take appropriate steps such as eradication, containment and control, to mitigate adverse effects. Techniques used for eradication, containment or control should be safe to humans, the environment and agriculture as well as ethically acceptable to stakeholders in the areas affected by the invasive alien species. Mitigation measures should take place in the earliest possible stage of invasion, on the basis of the precautionary approach. Consistent with national policy or legislation, an individual or entity responsible for the introduction of invasive alien species should bear the costs of control measures and biological diversity restoration where it is established that they failed to comply with the national laws and regulations. Hence, early detection of new introductions of potentially or known invasive alien species is important, and needs to be combined with the capacity to take rapid follow-up action.

Guiding principle 13: Eradication

Where it is feasible, eradication is often the best course of action to deal with the introduction and establishment of invasive alien species. The best opportunity for eradicating invasive alien species is in the early stages of invasion, when populations are small and localized; hence, early detection systems focused on high-risk entry points can be critically useful while post-eradication monitoring may be necessary. Community support is often essential to achieve success in eradication work, and is particularly effective when developed through consultation. Consideration should also be given to secondary effects on biological diversity.

Guiding principle 14: Containment

When eradication is not appropriate, limiting the spread (containment) of invasive alien species is often an appropriate strategy in cases where the range of the organisms or of a population is small enough to make such efforts feasible. Regular monitoring is essential and needs to be linked with quick action to eradicate any new outbreaks.

Guiding principle 15: Control

Control measures should focus on reducing the damage caused as well as reducing the number of the invasive alien species. Effective control will often rely on a range of integrated management techniques, including mechanical control, chemical control, biological control and habitat management, implemented according to existing national regulations and international codes.

Annex 2. List of 53 African countries that are parties to the Convention on Biological Diversity.

Algeria	Ethiopia	Niger
Angola	Gabon	Nigeria
Benin	Gambia	Rwanda
Botswana	Ghana	Sao Tome and Principe
Burkino Faso	Guinea	Senegal
Burundi	Guinea Bissau	Seychelles
Cameron	Kenya	Sierra Leone
Cape Verde	Lesotho	Somalia
Central African Republic	Liberia	South Africa
Chad	Libyan Arab Jamahiriya	Sudan
Comoros	Madagascar	Swaziland
Congo	Malawi	Togo
Côte d'Ivoire	Mali	Tunisia
Dem. Rep. of the Congo	Mauritania	Uganda
Djibouti	Mauritius	United Rep. of Tanzania
Egypt	Morocco	Zambia
Equatorial Guinea	Mozambique	Zimbabwe
Eritrea	Namibia	

Annex 3. The 30 African countries that are signatories to or have acceded to the Biosafety Protocol. Those marked with an asterix are parties to the Protocol.

Algeria	Gambia	Namibia
Benin	Guinea	Niger
Botswana	Kenya *	Nigeria
Burkino Faso	Lesotho *	Rwanda
Cameroon	Liberia *	Senegal
Central African Republic	Madagascar	Seychelles
Chad	Malawi	Togo
Congo	Mali	Tunisia
Egypt	Morocco	Uganda *
Ethiopia	Mozambique	Zimbabwe

* As of 26 March 2002, four African countries are parties to the Protocol. Kenya and Uganda have ratified the Protocol, while Lesotho and Liberia have acceded to the Protocol.

A Biosafety Approach to Addressing Risks Posed by Aquaculture Escapees

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Abstract

Aquaculture operations should include a comprehensive biosafety program because of the risks they may impose on biological resources in the environments into which cultured organisms may escape. Risk assessment incorporates hazard identification and risk analysis. Risk analysis encompasses describing the likelihood that a hazard and its consequences will occur and the severity of realization of a consequence. For aquaculture, four hazards have been identified: escapes of alien species, escapes of alien species that can hybridize with native species, escapes of cultured stocks into populations of the same species, and escapes of genetically engineered organisms. Consequences of the realization of these hazards may affect multiple levels of biodiversity, from genes to populations to communities. For escapes of cultured organisms, possible consequences and their likelihoods are described, along with the consequences that may range from extinction of native species to erosion of genetic diversity among populations. A complete risk management program includes developing risk reduction measures and a monitoring program to determine if such measures are adequate. Monitoring aquaculture operations to detect escapees and their ecological impacts makes it possible to: (i) detect the occurrence of a hazard and initiate remedial efforts to reduce its occurrence and minimize adverse consequences; and (ii) learn more about a given cultured stock's likelihood of imposing consequences, which can then be applied to the risk analysis of other aquaculture operations. Including all these elements in biosafety programs will lead to systematic evaluation and solid evidence of the degree of ecological safety versus risk of an aquaculture operation, as well as encourage adaptive mid-course corrections in existing biosafety measures and adaptive learning that will improve future biosafety decisions and measures.

Introduction

Aquaculture is an important source of food, employment, and revenue for many countries and communities. Starting in the 1950s, worldwide aquaculture production has increased at rates exceeding 5 per cent annually, and in recent years the annual increase has been more than 10 per cent (FAO 2000). Although the contribution of African aquaculture to global production has been low so far, it is expected to play an important role in the years to come to meet the increasing demands. Yet even though aquaculture shows promise for providing local and regional economic benefits in Africa, certain aquaculture systems and practices may also pose threats to the environment that, in turn, would undermine local communities' options for achieving sustainable livelihoods. Escapes of cultured alien species, selected or domesticated broodstocks, and transgenic organisms (genetically engineered organisms), in some cases, could adversely affect aquatic biological diversity, ranging from the genetic resources of extant native wild populations to ecological resilience of fish communities.

The paper addresses methods for assessing and managing ecological risks posed by escapes of cultured fish. First, the components of a comprehensive biosafety program are reviewed and then these components are applied to fish that might escape from an aquaculture operation. Such a comprehensive biosafety program has risk assessment and risk management components (Table 1) (Kapuscinski et al. 2001).

Risk Assessment

Risk assessment includes identifying hazards that denote events that could pose harmful consequences and quantifying risk that denotes the probability of a hazard occurring. Hazard identification is important because the rest of the risk analysis and management procedures depend on it. A full risk analysis goes beyond assessing the probabilities of hazards occurring. The next key tasks are to determine the consequences of realization of a hazard and the severity of these consequences. For aquaculture, these consequences may be economic or social, as well as biological. Thus social acceptance of risk decisions depends on explicit deliberation of different perspectives (Committee on Risk Characterization 1996; Nowotny et al. 2001). Evaluating severity will be a value-laden process. The Royal Society of London (1992), for example, characterized risk assessment as identifying hazards, quantifying them, and allowing for values and perceptions of risk. Severity will also be affected by the extent to which feasible options exist for mitigating the hazard. For example, the extirpation of a population may eliminate a valuable fishery in the short-term. However, if the species has nearby populations that can recolonize the system in the long run, loss of the local population will be less severe than the extirpation of the last population of a species.

The risk assessment can be summarized as a matrix of likelihood plotted against severity of consequence (Figure 1). Clearly, great effort should be made to avoid hazards with a high probability of occurrence and most severe consequences (Figure 1, upper right corner). The second level of priority regarding the three remaining cells in Figure 1 is harder to set and requires an answer to the question, "should we address low probability hazards of high severity or high probability hazards with less severe consequences?" The answer should be reached through deliberation among legitimate representatives of all potentially affected parties. Finally, scientists and other relevant technical experts should judge the certainty of the knowledge used for the analysis in order to prioritize risk reduction measures, and identify information required to complete a full risk assessment.

Risk Management

Risk management involves planning and implementing risk reduction measures and monitoring to determine if the risk reduction is working. Risk reduction measures can either reduce a hazard's likelihood of occurrence or reduce the severity of its consequences. Monitoring projects

Table 1. Systematic steps of risk assessment and management, essential but not sufficient parts of an analytic deliberative framework of risk characterization and decision-making (modified from Kapuscinski et al. 2001).

Step in risk assessment and management	Key question addressed at this step
Hazard identification	What event posing harmful consequences could occur?
Risk analysis	How likely is the hazard?
	What would be the consequences of the hazard and how severe are they?
	What is the risk assessment, i.e., a matrix of likelihood plotted against severity of consequence? Each cell of the matrix should be accompanied by a qualitative assessment of the response and level of assurance needed to reduce harm if the cell's conditions were to occur.
	How certain is the knowledge used to identify the hazard, estimate its likelihood, and predict consequences?
Risk reduction planning and implementation	What can be done to reduce risk, either by reducing the likelihood or mitigating the consequences of hazard realization?
Risk tracking (monitoring)	How effective are the implemented measures for risk reduction.
	Are they as good, better or worse than planned for?
	What follow-up / corrective action / intervention will be pursued if findings are unacceptable?
	Did the intervention adequately resolve the concern(s)?

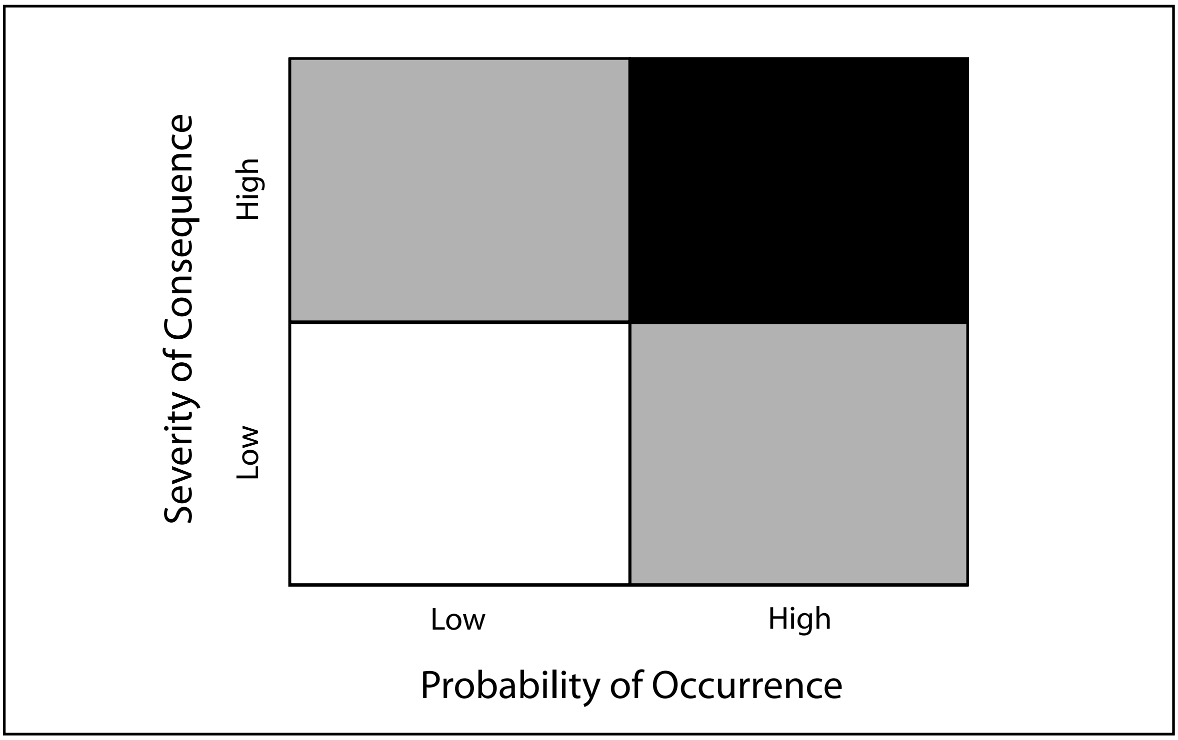

Figure 1. Schematic of a risk assessment matrix. Hazards of greatest concern are those with high probability of occurrence and high severity of consequences (black area). Social and economic considerations will influence the priority given to hazards in the gray area. Depending on the quality of information available, the axes could be continuous values or more refined categories (for example a 3 x 3 matrix of high-medium-low rankings).

that move forward based on risk decision-making is the only way to achieve adaptive improvements in future risk assessment and management. Monitoring can be used to detect the occurrence of hazards and signal the need for either stopping, revising, or mitigating current practices. In this role, it is important to conduct monitoring at a point early enough in the process to allow for effective remedial actions. The realization of certain hazards rules out any possibility of mitigation. In this situation, monitoring may provide information about the severity of consequences that can be used for improved future risk analyses of similar situations.

Who Participates in Biosafety Programs?

The history of safety programs for technologies whose products offer clear societal benefits, but also pose public harm has demonstrated the need for safety programs to be, as Gibbons (1999) would say, "both scientifically reliable and socially robust" (Kapuscinski et al. 2001). Good science, therefore, is necessary and indispensable, but not sufficient for establishing credible and effective biosafety programs addressing various environmental concerns in aquaculture. A broad cross-section of potentially affected and interested parties needs to collectively deliberate on key elements of biosafety programs (Committee on Risk Characterization 1996; Kapuscinski et al. 1999).

The most durable way to achieve broad participation and support is to develop biosafety programs through an iterative analytic-deliberative process (Committee on Risk Characterization 1996; Kapuscinski 2001). Analysis uses scientifically reliable methods to arrive at answers to factual questions (for example, the questions listed for risk analysis in Table 1). Inter-disciplinary teams of scientists, scientific studies, and tools designed to assist risk decision making (for example, Agricultural Biotechnology Research Advisory Committee 1995; Brister and Kapuscinski 2002; Scientists' Working Group on Biosafety 1998) play the dominant role in analysis. Deliberation uses processes such as discussion, reflection and persuasion to communicate, raise and collectively consider issues, increase understanding, and arrive at substantive decisions.

Public officials, scientists, and potentially affected and interested parties participate through iterations of analysis and deliberation. For the issues addressed in this paper, potentially affected and interested parties might include: local farmers interested in introducing a new genetic variety or new species of fish into their farms; local subsistence, recreational and commercial fishers; public officials responsible for governing aquaculture, fisheries and other aquatic natural resources; and fisheries scientists with expertise in population genetics, conservation biology, fish population dynamics, and aquatic ecology. They may also include other people whose livelihoods depend directly or indirectly on healthy fish communities in the water bodies they customarily access. Such a broad cross-section of parties should first deliberate on problem formulation, i.e., defining what events they agree are "hazards" and what possible outcomes they agree are "harmful consequences", as well as criteria for determining the "severity" of a consequence. Analysis of scientific principles and evidence, as laid out in this paper, provides an essential point of departure for these deliberations. Broader deliberation on problem formulation, however, is equally essential in order to assure that all affected parties will accept and abide by the ultimate risk and safety decisions. It is likewise important to link scientific analysis and cross-sectoral deliberation in designing, reviewing, and updating (based on new information) all components of a biosafety program outlined in Table 1. For example, if these different parties first deliberate to reach agreement on acceptable versus unacceptable levels of the likelihood of different risks, then they are more likely to reach durable agreement on risk reduction and mitigation measures and to pro-actively help implement such measures.

In what follows, the paper outlines the essential components of a risk assessment and management program for aquaculture of alien species and genetically enhanced broodstocks. First four types of hazards associated with the escape or intentional introduction of organisms from an aquaculture facility are identified. Then a range of possible consequences, with an emphasis on ecological results, and ways of determining their likelihood of occurrence are discussed. Risk management involves risk reduction and monitoring. Several approaches to reducing risk from aquaculture escapees, either by minimizing the likelihood or mitigating the consequences are suggested. Finally, concluded with a discussion of monitoring that may be used to detect escaped organisms or to evaluate the severity of consequences due to their escape.

Risk Assessment for Escapes of Alien Species and Genetically Enhanced Broodstocks

The types of hazards imposed and the potential consequences to aquatic resources depend on the species cultured and the species present in the environment in which cultured species might escape or be stocked. Ideally, one should begin a risk analysis at an early point in the planning of an aquaculture operation because the choice of species and facilities will affect the likelihood of escapes at the outset. For discussion purposes, however, the paper begins with an analysis of risks at the point of escape (or stocking) of the cultured species. Four types of hazards imposed by cultured organisms are distinguished and the risks and consequences of these hazards are discussed.

Hazard Identification

The types of hazards imposed and the potential consequences to aquatic resources depend on the species cultured and the species present in the environment into which cultured species might escape or be stocked. The escape of an alien species with no close relatives with which to hybridize (Hazard I) may impose drastic effects on aquatic communities. Although aliens will impose no direct genetic consequences through interbreeding, they may act indirectly on genetic resources by reducing the abundance of another species, even to the point of extirpation. The escape of aliens that have close relatives with which they can hybridize (Hazard II) may impose the same consequences as aliens without relatives, with the addition of direct genetic consequences through interbreeding. The escape of aquaculture strain of native species into environments harboring populations of the same species (Hazard III) may alter the genetic diversity and fitness of the wild population. Finally, the escape of genetically engineered organisms (Hazard IV), which may fit into any of the hazards above, introduces additional concerns that merit attention.

Risk Analysis

Hazard I: Escape of alien species - invasion without hybridization

The ecological consequences of invasive alien species (Hazard I) may range from integration into the local community with few observable effects to extirpation of native species (Moyle and Light 1999). In between these extremes are cases where alien invasions alter the abundance or behavior of species in the invaded community. For instance, Lever (1996) reviewed the impacts of tilapia species introduced throughout the world and found that ecological consequences included extirpation of native species, numerical domination of fish communities, and alteration of water quality and aquatic vegetation that indirectly affects many other parts of the community.

The risk of an alien species invasion causing harm is the product of two components: the likelihood that an alien species will become established, multiplied by the likelihood that an adverse consequence will occur if it does become established. Invasions of alien species have been the foci of much empirical and theoretical interest (Moyle and Light 1999; Parker et al. 1999; Williams and Meffe 2000), including the role of aquaculture as a "gateway for alien species" (Naylor et al. 2001). Unfortunately, this work shows that it is difficult to predict the likelihood of invasion by a specific species into a given environment, and even more difficult to predict the consequences of an invasion. Nevertheless, a careful evaluation of the characteristics of the species and the potential receiving environment will aid in assessing the risks of the alien species. In addition, the history of the species' success as an invader elsewhere (for example Lever 1996; Bartley et al. 1998) will suggest its likely invasiveness potential.

Hazard II: Escape of alien species – with possibility of hybridization

The consequences of alien species escaping into waters with wild relatives are similar to those posed by Hazard I. However, Hazard II can lead to additional genetic alterations of populations of native species through hybridization. If escapees are capable of interbreeding with native species and producing viable hybrid descendants, introgressive hybridization can result in a complete loss of the uniqueness of the gene pool of a population, subspecies or species, resulting in a "hybrid swam". The loss of this level of genetic diversity may reduce the evolutionary potential and thus the long-term existence of the native populations, as well as reduce options for aquaculture breeding programs that depend upon the local gene pools. In extreme cases, a native species gene pool will be replaced by alien or hybrid genetic materials, thus leading to extinction of a species (Scribner 2001, and citations therein). For some species, genetic intermixing may not continue into advanced generations because of sterility or low fitness of hybrids. Over time, natural selection should remove many of the alien genes in the population. Intermating, however, will result in the "wasting of reproductive efforts" of native species when they contribute to offspring exhibiting reduced fitness.

Risks due to hybridization are a product of the likelihood of interbreeding between aquaculture escapees and native populations, and the likelihood of the consequences described above. Determination of the likelihood of gene flow from aquaculture populations to native fish populations requires information about life histories, especially reproductive biology (for example behavior and timing) and spawning habitat use, for both aquaculture species and closely-related species in the wild. Natural hybridization among fish in closely related taxa is relatively common because of external fertilization, weak behavioral reproductive mechanisms, unequal abundance of two parental species, competition for limited spawning habitats, and secondary contact of recently evolved species. Campton (1987) and Lowe-McConnell (2000) reviewed a number of cases where tilapian species hybridize when stocked together in an aquatic system. The likelihood of hybridization may also fluctuate over time due to the changing demographics of aquaculture and native fish populations. For example, if the number of escaped individuals, either introduced species or interspecific hybrids, overwhelms the number of native fish species, the native fish may interbreed with escapees at higher frequencies due to higher encounter rates even if they prefer to mate with conspecific counterparts.

Hazard III: Escape of aquaculture strain of native species into environments with populations of the same species

The consequences of escaping native species will depend in part on the genetic differences between the escaping strains and the wild population. Most fish species, especially in fragmented and isolated freshwater systems, are made of multiple populations with varying levels of genetic differentiation among them. For example, growth traits (partly genetically controlled) differed for strains of *Oreochromis niloticus* from various parts of Africa (Penman and McAndrew

2000; Seyoum and Kornfield 1992). They could distinguish the seven subspecies of *O. niloticus* using molecular genetic markers. There are two possible consequences of aquaculture escapees interbreeding with genetically-structured natural populations: firstly, homogenization of genetic differences between populations that might reduce the long-term persistence of natural populations; and secondly, outbreeding depression, a reduction in fitness and thus productivity of offspring from parents that are genetically dissimilar. In addition, domestication of aquaculture stocks necessarily causes genetic changes in them that can contribute to a decline in fitness upon intermating with wild populations (see Waples 1995 for a review of the genetic basis for outbreeding depression in wild fish populations).

The risk imposed by escapes of cultured fish of a native species is the product of the probability of escapees replacing or interbreeding with wild fish multiplied by the probability of the two consequences, loss of evolutionarily important genetic differences among populations, and outbreeding depression. The probability of interbreeding by escaped fish will depend on their entry potential (for example frequency of escapes at different seasons, and distance to area with wild populations) and the introgression potential (for example survival to reproductive stage; similarity in reproductive development; timing of spawning and mating behavior of cultured and wild fish; and survival of offspring). In many cases, one can assume that the aquaculture escapees will interbreed, and thus directly interact genetically with wild populations. Risk analysis then focuses on the probability of realizing negative consequences of intermating.

The probability of negative consequences due to interbreeding of cultured strains and wild populations of a native species increases as genetic differences between the cultured and wild groups increase. Greater differences arise from longer and more complete isolation between populations and from more strongly discordant selective pressures in different environments. An aquaculture broodstock and a wild population may differ genetically because the broodstock derives from a non-local population that is genetically different from the one in the local environment (i.e., has evolved separately) or because of genetic changes in the aquaculture environment (i.e., random change due to genetic drift or selective differences between the aquaculture and natural environment). The probability of negative consequences can be reduced if the cultured stock is derived from a local population, and thus has a similar genetic background. Cultured organisms, however, will become domesticated as selective forces genetically adapt them to the aquaculture environment. As domestication increases, adaptation to the natural environment decreases, raising the likelihood of outbreeding depression even if the wild population was the founding source for the aquaculture broodstock.

Hazard IV: Transgenic organisms (genetically engineered organisms)

Transgenic fish represent special cases of Hazards I-III, and thus their escape from aquaculture facilities may lead to the consequences of aquaculture escapes described above. Of importance to risk analysis of transgenic escapees is whether or not the novel traits they express alter the probability or severity of consequences they might impose on natural populations. To determine this, risk analysis of transgenics requires evaluation of the net fitness of transgenic escapees.

Net Fitness: The term net fitness is scientific shorthand for the degree to which an organism succeeds at passing on its genes to future generations. Net fitness is fully determined by the joint effect of six fitness traits of the organism: juvenile and adult viability (chances of surviving to sexual maturity and surviving to procreate additional times), fecundity (number of eggs produced by a female), fertility (per cent of eggs successfully fertilized by male sperm), mating success, and age at sexual maturity (Muir and Howard 2001a). The notion that survival alone determines the spread of transgenes - hence transgenic organisms exhibiting reduced survival always pose no environmental hazard - is wrong; the likelihood and degree of transgene spread following an escape from an aquaculture facility depends on the net effect of all six fitness traits (Muir and Howard 2001; Rodriguez-Clark and Rodriguez 2001).

Transgenic Alien Species Invasion: Alien species invasion is a possible consequence if transgenic fish enter a suitable ecosystem that lacks wild relatives. Fertile transgenic fish are likely to establish a self-regenerating population of the alien species if their invasive ability, as a direct or indirect effect of their engineered genes, is greater than or equal to that of the unmodified invasive parental species. One major indicator is if the net fitness of the transgenic fish line is equal to or greater than that of the unmodified parental line. An example of a transgenic fish with a novel trait that might alter net fitness is a line of goldfish with antifreeze protein transgenes giving them increased cold tolerance (Wang et al. 1995). Large-scale production of such goldfish would raise the possibility that they would greatly increase the range of water bodies invaded by this goldfish, already an established alien in some inland waters, and, through their prolific breeding and hardy nature, become a greater nuisance.

Gene Flow from Transgenics to Wild Relatives: Gene flow is a potential consequence if fertile transgenic fish enter water bodies with wild relatives of the same or related species and interbreed with wild relatives. Recently published research suggests three plausible scenarios of gene flow (Muir and Howard 2001, 2001a). In a purging scenario, the net fitness of a transgenic fish is much lower than that of its wild relatives and natural selection quickly purges any transgenes inherited by wild relatives. This is the safest scenario in that it does not pose adverse environmental consequences. In a spread scenario, gene flow would lead to spread and persistence of the modified trait in the wild population if the transgenic fish have equal or higher net fitness than their wild relatives. Recent studies suggest that age at sexual maturity has the greatest effect on net fitness (and thus transgene spread), followed by juvenile viability, mating advantage, female fecundity, and male fertility (Muir and Howard 2001; Rodriguez-Clark and Rodriguez 2001). For example, transgenic fish with greatly reduced viability but with an earlier age at sexual maturity or sufficiently fitness-enhancing changes in other fitness components could still spread their transgenes. The spread scenario may lead to the displacement of the wild population by descendants of the transgenic escapees. Alternatively, temporary spread of a transgene may lead to a surprising third outcome, the "Trojan gene" scenario.

If a transgenic fish line exhibits both a large mating advantage and a moderate viability disadvantage compared to wild relatives, but the large mating advantage overwhelms the viability disadvantage, recent research predicts a dramatic outcome of gene flow. The mating advantage drives the transgenes into the wild population, spreading them rapidly throughout the population, but the lower survival of each consecutive generation carrying the transgenes eats away at the population size. Research predicts that this "Trojan gene effect" would trigger a rapid decline of the wild population (Muir and Howard 1999, 2001). Unless the decline is stemmed by human intervention or by sufficiently strong, counteracting natural selection, the wild population will become extinct. Other scenarios can be envisioned in which trade-offs among the fitness component could lead to "Trojan gene" effects.

Risk Reduction

Risk reduction planning and implementation comes into play whenever hazard identification and risk analysis have led to the conclusion that escapes of organisms from aquaculture operations will impose an unacceptably high likelihood of a particular hazard multiplied by the severity of possible consequences. The first decision to make in risk reduction planning is whether to aim for reduction or mitigation of each risk at issue. Mitigation differs substantially from risk reduction in that it simply accepts the risk and focuses on designing measures to compensate for the harmful consequences. Reduction, in contrast, does not accept risk wholesale, but rather focuses on managing it by greatly reducing the likelihood of hazard realization.

Redundant Design for Risk Reduction

In many technology applications, the principle of "redundancy" guides efforts to reduce the realization of predicted hazards. Redundant design for reducing risks posed by escapes from aquaculture operations involves applying a mix of different types of confinement measures, where each type has a fundamentally different vulnerability to failure (for example, as recommended by Brister and Kapuscinski 2002; Kapuscinski and Brister 2001; and the Scientists' Working Group on Biosafety 1998). By mixing confinement measures with different vulnerabilities, one increases the chances that failure of one barrier will not breach all the barriers to escape of organisms from the aquaculture operation. Physical barriers induce 100 per cent mortality through such physical alterations as imposing lethal water temperatures or pH to water flowing out of fish tanks or ponds before the effluent is discharged to the environment. Mechanical barriers are devices, such as screens, that hold back any life stage of the organism from leaving the aquaculture facility. Biological barriers, such as induced triploidy that makes adults of some fish species functionally sterile, are those that prevent any possibility of the organism reproducing or surviving in the natural environment.

Two possible approaches to risk mitigation for escapees from aquaculture are localization and use of local fish as broodstock (Hindar et al. 1991). Localization is the confinement of aquaculture operations to designated areas so that the geographic range of impacts is reduced. Use of local broodstocks minimizes genetic differences between escaping and natural fish, which reduces the likelihood of harmful fitness effects from interbreeding. Risk still exists because of genetic changes due to domestication during hatchery rearing, but this option will prevent the introduction of highly alien genes, and pathogens, into the natural populations.

Risk Tracking (Monitoring)

Monitoring aquaculture operations to detect escapees and their impacts can serve two roles. Firstly, monitoring can determine if the risk reduction measures were adequate; when risk reduction measures prove to be worse than planned for, this information can guide responsible parties to develop and implement corrective action; and, finally, determine if corrective action adequately resolves the concern(s). Table 1 focuses on this first role of monitoring. Secondly, monitoring can aim to learn more about a given species or cultured stock's likelihood of imposing or not imposing adverse consequences. It provides important new knowledge that can then improve future risk analysis of other aquaculture operations. The desired role of monitoring will drive decisions regarding the types and duration of steps taken.

Reference Points

While planning for risk monitoring, it is important to establish reference points that trigger corrective actions (Caddy and Mahon 1995). For aquaculture, reference points should address conditions of escape (such as number of escape events, number of escapees), gene flow (for example presence of hybrid offspring), and population and community dynamics (for example, percentage of declines in species abundance or diversity). For example, monitoring could determine if the numbers of fish escaping from a given aquaculture facility has remained below, at, or above the level chosen as a risk reduction measure. If monitoring detects numbers of escapees above the desired level, then decision makers would implement corrective actions. Generally, corrective actions could attempt to remove escaped organisms from the natural environment, limit their movements in order to halt wider dispersal of escapees, and alter operations to minimize chances of future escape or to reduce the likelihood of adverse consequences from escapees. Biosafety planning should identify corrective actions and personnel responsible for implementing the actions for each reference point established.

Importance of Baselines

Key to any monitoring of impacts on natural populations is baseline information about the natural communities possibly affected by an aquaculture operation. This begins with knowledge of the species present and, preferably, some idea of their abundance. Knowledge of the species present is necessary to monitor for extirpations (i.e., a potential adverse consequence) and, if there are closely related species present, for undesired hybridization between one or more of them and escapees from aquaculture operations. Abundance estimates - at least rough measures such as catch per unit effort in an experimental netting, relative abundance in fishery catches or experimental sampling - are also needed to provide a baseline for monitoring changes in the fish community structure when the changes are less drastic than complete extirpations.

Baseline genetic profiles are necessary to monitor gene flow. In cases of hybridization, species-specific genetic markers must be identified. For example, protein, mtDNA, and nuclear DNA species-specific markers are available for many tilapia species (Penman and McAndrew 2000). In cases of interbreeding within a species, genetic differences between cultured and natural populations must be identified and quantified. Natural populations throughout a species range should be sampled to reveal the existing population genetic structure (between-population genetic variation) within species. Specific DNA markers for genetically modified organisms can easily be developed from unique sequences within the inserted DNA construct (from the protein-encoding gene or promoter sequences). Baseline profiles with several genetic marker types are preferable, because the cost and ease of application and the level of resolution will differ between types (for example microsatellite DNA markers typically reveal more variation and higher resolution than proteins, but cost more). DNA markers amenable to polymerase chain reaction (PCR) amplification can be applied with minimal amounts of tissue, including air-dried fish scales or fin samples. If resources are not immediately available for genetic analyses, samples such as these could be archived (Rivers and Ardren 1998) for future analysis as the need arises (for example a new aquaculture facility or species is proposed).

Conclusion

A comprehensive aquaculture biosafety program must incorporate assessment and management of risks associated with escapes of aquatic organisms. The realization of a hazard (i.e., an escape event) can initiate a cascade of consequences that may harm biodiversity and other ecological resources, and ultimately the social and economic welfare of affected parties. Proposed and ongoing aquaculture operations should be assessed in terms of the likelihood that a hazard and its consequences will occur, and the severity of the consequences. The identification of hazards those are likely to be realized or have severe consequences signals the need for risk reduction measures and a monitoring program to determine if such measures are adequate. Aquaculture programs operated with a commitment to biosafety during planning and operations offer the promise of food, jobs, and income, while maintaining biodiversity and ecological integrity in the surrounding natural environment.

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Quarantine Procedures and Their Implementation[1]

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Abstract

Diseases have become one of the most significant constraints to aquaculture development and management worldwide. It is clear that most disease incursions and outbreaks stem from unregulated movement of aquatic animals, with little or no risk assessment and quarantine. The way to reduce the introduction of pathogens and occurrence of disease outbreaks is to apply appropriate international norms, recommendations, and standards that govern safe trans-boundary movement of aquatic animals and animal products. This paper discusses the various international conventions and agreements dealing with safe trans-boundary movement and the requirements for better quarantine as part of the process.

Introduction

Quarantine measures are outlined in most codes on introduced fish. Policies dealing with the introduction of aquatic species, including methods to minimize disease transfers, have also been developed by the International Council for the Exploration of the Sea (ICES) for marine introductions (ICES 1995). The World Organisation for Animal Health (OIE) has also developed recommendations and protocols for the international prevention and spread of specific diseases of aquatic organisms, as described in the Aquatic Animal Health Code and Manual (OIE 2003a; OIE 2003b). This also includes protocols for health surveillance of animals for domestic and international trade. Major international codes and guidelines for aquatic animal health and movement of aquatic animals include:

- The World Animal Health Organisation (OIE) Aquatic Animal Health Code and Manual (OIE 2003a; OIE 2003b);
- Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals (FAO 2000);
- The ICES Code of Practice on the Introductions and Transfers of Marine Organisms - 1994 (ICES 1995);
- The International Council for the Exploration of the Sea (ICES) and the European Inland Fisheries Advisory Commission (EIFAC) Codes of Practice and Manual of Procedures for Consideration of Introductions and Transfers of Marine and Freshwater Organisms (Turner 1988);
- The ICES Guidelines for the Implementation of the ICES Code of Practice concerning Introductions and Transfers of Marine Species (ICES 1984); and
- The ICES Overview of Current Molluscan Disease Control Measures (ICES 1991).

There is an enormous number of cases where parasites and diseases have been spread to new regions by human activity. Most well-documented cases involve international movements and diseases introduced with exotic species to the receiving waters. Despite these examples and the codes and protocols described above, fish and shellfish continue to be introduced into new areas, with little consideration of the potential disease consequences. Additionally, transfers (movements of aquatic animals to areas within their areas of historical distribution) are commonly regarded as less risky, and thus are poorly documented, which complicates investigation of concurrent movements of pathogens and parasites. It should be noted, however, that there are equally significant health risks associated with transfers of aquatic animals within their geographic range. A population that is adapted to a specific pathogen can carry it with no sign of infection. There is a

[1] This paper is drawn from the material and information provided in two recent publications dealing with aquatic animal health management strategies for the responsible movement of live aquatic animals in the Asia-Pacific region. The information provided in these documents is highly relevant to the other regions of the world, including Africa. The documents referred to are: (i) FAO/NACA. 2000. Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals and the Beijing Consensus and Implementation Strategy. FAO Fisheries Technical Paper No. 402. FAO, Rome, 53 p.; and (ii) FAO/NACA. 2001. Manual of Procedures for the Implementation of the Asia Regional Technical Guidelines on Health Management for the Responsible Movement of Live Aquatic Animals. FAO Fisheries Technical Paper No. 402. Suppl. 1. FAO, Rome. 106 p.

high risk of disease outbreak if that pathogen is introduced to a naive (non-adapted) population of the same host species.

International Conventions and Codes of Practice

Policies, legislation, practices and guidelines concerning aquatic animal health and the movement of live aquatic animals are in a state of constant change. Frequent revisions and modifications are necessitated by: (i) rapid worldwide developments in aquaculture and culture-based fisheries; (ii) increasing knowledge on diseases of aquatic animals; (iii) improved or new diagnostic tools; and (iv) improved pathogen detection procedures. In addition, changing trade patterns that reflect changes in the political, social, industrial, and economic environments of individual countries and regions also contribute to the dynamics of risk assessment sensitivity. As an adjunct to national legislation, policies, guidelines, and codes of practice have been developed by international agencies or working groups with responsibility for aquatic animal disease control. These have been developed to provide a degree of international standardization for the prevention of pathogen transfer with movements of live aquatic animals. Box 1 shows some of the major international initiatives. There are also relevant items within the Code of Conduct for Responsible Fisheries (CCRF), the Convention on Biological Diversity (CBD), and the World Trade Organization's (WTO) Sanitary and Phytosanitary Agreement.

Box 1. Major international codes and guidelines for aquatic animal health and movement of aquatic animals.

- The World Animal Health Organisation (OIE) *Aquatic Animal Health Code* (OIE 2003a).
- The *ICES Code of Pratice on the Introductions and Transfers of Marine Organisms - 1994* (ICES 1995).
- The International Council for Exploration of the Sea (ICES) and the European Inland Fisheries Advisory Commission (EIFAC) *Codes of Practice and Manual of Procedures for Consideration of Marine and Freshwater Organisms* (Turner 1988).
- The ICES *Guidelines for the Implementation of the ICES Code of Pratice Concerning Introducing and Transfers of Marine Species* (ICES 1984).
- The ICES *Overview of Current Molluscan Disease Control Measures* (ICES 1991).

FAO Code of Conduct for Responsible Fisheries (CCRF)

"States should, in order to minimise risks of disease transfer and other adverse effects on wild and cultured stocks, encourage adoption of appropriate practices in the genetic improvement of broodstocks, the introduction of non-native species, and in the production, sale and transport of eggs, larvae or fry, broodstock or other live materials. States should facilitate the preparation and implementation of appropriate national codes of practice and procedures to this effect."

Government representatives at the FAO Conference adopted this voluntary code in October 1995, with the objective of providing a framework to ensure national and international exploitation of aquatic living resources in sustainable harmony with the environment. Article 9 of the code refers specifically to aquaculture and provides several principles relating to aquatic animal disease control. Article 9.3.3 is particularly relevant. The CCRF also emphasizes:

- The importance of cooperation with neighboring states in the introduction of species in trans-boundary aqatic ecosystems (Article 9.2);
- The need to establish databases and information networks to collect, share and disseminate aquaculture data, at national, regional and global levels (Article 9.2.4); and
- The need for cooperation in the elaboration, adoption and implementation of international codes of practice and procedures for introductions and transfers of aquatic organisms (Article 9.3.2).

Significantly, Article 9.4 also identifies the importance of producers (such as farmers, fishery stakeholders, etc.) in the development and implementation of practices for the responsible development of aquaculture, including aquatic animal health management and disease control.

Convention on Biological Diversity

The Convention on Biological Diversity (CBD) was opened for signature on 5 June 1992 at the United Nations Conference on Environment and Development (the Rio "Earth Summit"). The Convention, which came into force on 29 December 1993, emphasizes the conservation and management of aquatic animal biodiversity. This includes clear recognition of the importance of protocols to minimize the negative impact on aquatic biodiversity due to the movement of exotic species and uncontrolled spread of aquatic animal pathogens. The parties to the CBD agreed on a program of action for implementing the CBD with respect to marine and coastal biodiversity at their second conference, held in Jakarta in 1995. This program, termed the "Jakarta Mandate on Marine and Coastal Biodiversity", contains five "Action Items". Two are directly relevant to the development of these regional guidelines: Action Item 4: "Ensure that mariculture operations are sustainable", and Action Item 5: "Prevent introduction of, and control or eradicate, harmful alien species". The latter identified introductions of pests and diseases with alien species as important risks that should be assessed and managed (de Fontaubert et al. 1996).

The Jakarta mandate also recommended the implementation of the articles of the Code of Conduct for Responsible Fisheries (FAO 1995) and of international guidelines. Also recommended was the development of databases to share information on important pathogens to assist risk assessments.

The Aquatic Animal Health Code

The World Animal Health Organisation (OIE), an international veterinary organization with 165 member countries, has recently revised recommendations and protocols for the prevention of the international spread of diseases of fish, mollusks, and crustaceans in its Aquatic Animal Health Code (OIE 2003a). The principal policy of the OIE is to facilitate international trade in animals and animal products, including aquatic animals and their products, on the basis of health control and preventative measures. The OIE also recognizes public health issues connected to the consumption of animal products, for example drug residues, radioactive pollution, and related health risk analyses. The OIE Code was first published in 1995 and is regularly revised with the last version published in 2003.

ICES/EIFAC Code of Practice

Recommendations for policies dealing with the introduction of aquatic species and guidelines for their implementation, including methods to minimize the possibility of disease transfers, have also been developed by the International Council for the Exploration of the Sea (ICES) and the European Inland Fisheries Advisory Commission of the FAO (EIFAC) (Anon. 1984; Turner 1988; Carlton 1993). These documents detail codes of practice for the transfer of live aquatic organisms, including inspection, certification, quarantine, pathology, and environmental impact.

Additional ICES Codes and Guidelines

The Revised 1990 ICES Code of Practice to Reduce the Risks of Adverse Effects arising from the Introduction and Transfers of Marine Species was developed by the ICES Working Group on Introductions and Transfers of Marine Organisms (Carlton 1993). This Code of Practice is divided into five major parts: (i) a recommended procedure for assessment of all new species for introductions; (ii) actions regarding introductions; (iii) use of strict quarantine measures[2]; (iv) species involved in current commercial practice; and (v) different approaches toward the selection of the place of inspection and control of the consignment.

The ICES (1991) Overview of Current Molluscan Disease Control Measures recognized the rapidly expanding aquaculture industries based on mollusks, difficulties in the treatment and control of disease outbreaks in mollusks in open waters, and demands for transfers and introductions of indigenous and non-indigenous molluskan species. It noted considerable diversity among countries in disease control and quarantine legislation, and concluded that certification practices and procedures were of questionable value and required better definition regarding sampling regimes, numbers, and methods for disease detection.

Guiding Principles

When FAO developed the Asia Regional Technical Guidelines, they were based on a set of Guiding Principles. They are:

1. Movement of living aquatic animals within and across national boundaries is a necessity for economic, social, and development purposes.

2. Such movements may lead to the introduction of new and emerging pathogens and to disease establishment and, therefore may pose risks to the importing country's animal, plant, and human health status.

3. The role of health management is to reduce the risks arising from the entry, establishment or spread of pathogens

[2] Strict quarantine facilities differ from quarantine holding facilities used for low risk or routinely transferred aquatic animal species.

to a manageable level with the view to protecting animal, plant, and human life. Health management should also protect living aquatic resources, the natural aquatic environment and aquatic biodiversity, as well as support the movement of aquatic animals and protect trade.

4. The health management process is defined, in the broad sense, as aquatic animal health management encompassing pre-border (exporter), border, and post-border (importer) activities, as well as relevant national and regional capacity-building requirements (infrastructure and specialized expertise) for addressing health management activities, and development and implementation of effective national and regional policies and regulatory frameworks to reduce the risk of disease spread through movements (intra and international) of live aquatic animals.

5. Health management measures should be practical, cost-effective and easy to implement by utilizing readily available facilities. Individual countries may need to adopt, modify or vary these Technical Guidelines to suit their own particular situations and resources.

6. The varying capacity of developing countries to implement programs on health management should be acknowledged by relevant international organizations and financial institutions. These organizations should give full recognition to the special circumstances and requirements of many developing countries.

7. Health management measures will be based on an assessment of the risk to animal, plant, and human life or health. In assessing the risk, the prevalence of specific pathogens in both the region of origin and the region of destination are crucial issues. The likelihood of new or emerging pathogens becoming established in the region of destination is a major consideration.

8. All movements of aquatic animals should be conducted within the provisions given in existing relevant international agreements and instruments. Health management measures should not be applied in a manner that would constitute a disguised restriction on trade. Health management measures should be applied only to the extent necessary to protect animal, plant or human life or health, and must be based on scientific principles and not be maintained without sufficient scientific evidence.

9. In determining the appropriate level (stringency) of health management measures to be applied, relevant economic and ecological factors have to be taken into account. These are, *inter alia*: potential damage due to loss of production or value, and the cost of control or eradication. A conservative approach should be adopted in cases where insufficient knowledge exists in relation to disease risks posed by a particular import; a higher stringency of health management procedures should be adopted where in adequate knowledge exists.

10. The first movement (introduction) of a new species into a different area will require special health management considerations in light of the need to evaluate scientific evidence regarding the risk of introducing pathogens to new areas.

11. Different regions should attempt to harmonize health management procedures to facilitate safe movements of aquatic animals within and between regions.

12. Considering the free movement of aquatic species in trans-boundary waterways, it is necessary to divide regions into manageable sub-regional units based on factors such as geography, hydrography, ecosystems, epizootiological surveillance and effectiveness of control for the effective implementation of health management procedures. The basis for the establishment of such units should be uniform, clear, and unambiguous.

13. Honest, conscientious and transparent reporting is essential for health management to be effective.

14. Technical cooperation among regional experts is essential to promote the exchange of information and expertise.

15. Collaboration among the governments, public institutions, and the private sector, including all stakeholders, is important to

achieve the full purpose of implementing effective health management. Opportunities for sharing the benefits of health management among all stakeholders should be explored.

Health Certification and Quarantine Measures

In view of the current freedom from many serious diseases, documented disease introductions elsewhere, and the economic importance of fisheries and aquaculture industries, a compelling case exists for health certification and the quarantine of aquatic animals for the African region. Health certification and quarantine should facilitate the movement of healthy aquatic animals, be practical, readily implemented, by using available facilities (where possible), and be cost efficient. It should not pose unjustifiable or excessive restrictions on trade.

Development of quarantine measures for a first-time introduction requires a detailed knowledge of the disease status of aquatic animals within the region, as well as the nature and range of specific exotic diseases that may affect, or be carried by, the candidate species. A national or regional database, which can be continuously updated as new information becomes available, will greatly assist in this process. Freedom from disease concerns, in this case, is best assessed by holding and observing animals in quarantine facilities, whereby testing for infectious agents can be undertaken at the same time as protecting surrounding water and aquatic animals from exposure to the potential introduced species or any living effluent from its holding facility (various mechanisms exist to ensure that effluent from quarantine facilities is sterile or directed away from surrounding waters for land-based disposal). Access to more specialized laboratories and resources may be necessary to diagnose certain diseases.

A minimum standard of health certification and quarantine should be applied to all movements, with increasing levels of stringency, as the risk of introducing disease increases. Classification into lower risk and higher risk categories is, therefore, essential.

Health certification and quarantine measures should be implemented on a case-by-case basis, taking into account all circumstances and factors relating to the proposed movement. A full disease history of the candidate species, including a detailed review of specific pathogens and their status in the country or region of origin, should be compiled.

Quarantine and health certification protocols should be developed in collaboration with fisheries scientists, veterinarians, quarantine authorities, and industry stakeholders. An advisory authority on quarantine and health certification, including such expertise, should be formed to report to the government and act as a forum for all issues relating to trans-boundary movement of live aquatic animals.

Since the development of quarantine and health certification protocols requires detailed knowledge of the disease status of aquatic animals within the region, national and regional databases should be developed and updated as new information becomes available. While such databases are under development, the disease status can be assessed by holding shipments of aquatic animals in quarantine and, where appropriate, treating them. Access to specialized laboratories and resources may be necessary to diagnose certain diseases.

Quarantine and health certification considerations should be treated separately from ecological and environmental or genetic concerns, since the latter do not, normally, fall within the capability of aquatic animal health specialists.

Health Certification Process

Health certification provides documented assurance that a stock of live aquatic animals to be moved from one area to another (usually trans-boundary) is free of disease agents of concern to the importing country. Such certification also provides documentation for the shipper, in the case of a subsequent disease outbreak. Both aspects of certification assist effective tracing of the source of infection and the control or prevention of repeat infections.

Certification, by definition, means that the signing authority takes responsibility for the accuracy of the statements made on the certificate. This is especially important when the certificate is a condition for issue of a transfer license under an established legal framework. This means that the signing authority has a legal, as well as moral, obligation to ensure that the statements included in the certificate are accurate to the best of his/her knowledge. Thus, the signing authority must have direct experience or authority over employees who provide the scientific advice upon which the authority decides whether or not to sign a health certificate. This requires:

- training in aquatic animal diseases of concern to importers;
- accurate knowledge of the health status of the source of the exports being certified; and
- accurate knowledge of the health status of the same and related species in the receiving waters.

Certificates signed by personnel with inadequate training and experiences provide little assurance against disease transfer. Such certificates are a liability to both the importer and exporter. It should also be noted that border checks for gross signs of disease, which currently form the basis for the issue of health certificates in many countries, are of little value in detecting most aquatic animal pathogens.

In many countries, current infrastructure may not permit immediate improvement of health certification and quarantine procedures. In addition, many living aquatic animals pose logistical complications for effective post-border quarantine processing. For such cases, an accurate pre-border risk assessment is the pivotal factor for deciding what level of quarantine is necessary. Alternative procedures, such as accreditation of hatcheries, grow out facilities, holding establishments, etc., should also be considered as mechanisms to reduce the risk of trans-boundary introduction of aquatic animal pathogens.

Quarantine Process

Minimum quarantine requirements

Minimum quarantine requirements are those applied to all transfers or introductions assessed as having a minimal risk of disease transportation. Additional measures will be required for cases with a higher risk of disease transfer. Minimum quarantine requirements include, but are not necessarily limited to:

- some mechanism of assurance (for example pre-border health certification) that the source is free of diseases of concern;
- border level examination for gross signs of disease and ill-health; and
- shipment rejection, or border containment, of any shipments showing signs of disease and ill-health that are not likely to be attributable to shipping stress or damage.

Levels of risk can be minimized through biological awareness, as well as physical infrastructure. Eggs, embryonic or juvenile life stages should be selected for transfer, where possible, since these generally carry fewer primary or sub-clinical infections than do adult aquatic animals, and they are generally easier than adults to maintain under quarantine conditions.

Candidate stocks should be transferred on a batch-by-batch basis, where a batch is defined as a group of animals of the same age, from the identical population, and maintained as a discrete group. Mixing of animals, water or equipment between batches means that, for disease-screening purposes, those batches must be considered as a single batch.

Duration of quarantine

It is not possible to stipulate the duration of quarantine evaluation or containment, since this will vary depending on the candidate species and the risks associated with its movement. Most protocols for international introductions recommend spawning under quarantine containment conditions, with the release of the F1 generation after the broodstock has passed health surveillance and diagnostic screening (for example see ICES 1995). This is applied mainly to first-time introductions or high-risk introductions. Introductions from sources that have passed a quarantine containment process may receive "approval" status if conditions do not change at the export site, reducing further quarantine requirements and/or duration.

Pre-transfer quarantine

Animals destined for transfer should be placed in a quarantine facility for health examination, certification, and disease testing, as required. Any therapeutant used must be reported to the Competent Authority (CA) of the importing country. Health examinations should include sub-sampling for pathogens at least once prior to transfer. The cause of any disease detected should be determined or the transfer aborted.

Post-transfer quarantine

Animals should enter quarantine in the importing country for health examination and disease testing. Depending on the risk assessment of the source, sub-samples may be taken for examination for specific infectious agents of concern. Any animal that shows signs of disease should be examined, and the cause of the disease determined. If the cause cannot be determined, or if pathogens or parasites of concern are found, the transfer should be aborted and transport materials disinfected or disposed of in a sterile manner. Closed circulation quarantine containment facilities, used for higher risk transfers, should be thoroughly disinfected following detection of disease.

Quarantine inspection procedures

To ensure compliance with all import conditions, an official appointed by the importing authority should inspect each consignment of animals on entry. The CA may have additional responsibilities to inspect for requirements other than health (such as contamination by other organisms, human health requirements, etc.).

Pathogen containment facilities

A pre-transfer facility should ensure minimal exposure to infection risks at the export site. Post-transfer facilities should ensure prevention of escape of any animals or their disease agents into waters of the importing country prior to health screening.

Physical security

Quarantine containment facilities used for introductions of high or unknown risk should be capable of preventing:

- entry by unauthorized people;
- loss or release of quarantined animals; and
- loss of contaminated water or equipment.

The facility should be located within, or close to, existing fisheries or animal health facilities and, preferably, should have 24-hour supervision. The facility should be lockable and access restricted to designated personnel.

Containment facility location

Tanks, ponds, pools or other containers of an appropriate size and volume for the aquatic animal species in transit should be isolated from aquaculture facilities, as well as municipal and open waters. Construction and siting should be such that, in the event of an accidental spill or discharge, no water, animals or equipment will gain access to surrounding waters.

Intake water

Intake water should be obtained from a clean, unpolluted source to prevent physiological stress or masking of infectious agents by opportunistic infections. Incoming water should be filtered, wherever possible, for pre-transfer quarantine, to prevent exposure to infectious agents during the pre-transfer. This is not required for the post-transfer facility, however filtered influent water is recommended for containment of high or unknown health risk animals. This helps in identifying the source of any disease outbreak that may occur during the quarantine containment period.

Discharge water

All water leaving a post-transfer quarantine facility should be regarded as potentially infected. Thus, effluent from high-risk aquatic animals should not be discharged directly into surrounding waterways. Effluent containment in a sump, reservoir or pond that permits chemical disinfection, or discharge into a land-based pit or pond, is recommended for such cases. Any chemically disinfected (for example chlorinated) water should be neutralized prior to release into the environment.

Containment facility equipment

All equipment used for high disease-risk transfers and introductions (such as nets, containers, pipes, hoses, pumps) should remain within the containment facility and not be removed or used for any other purpose unless disinfected.

Containment facility laboratory area

An enclosed area, which can be used as a laboratory, is necessary to prepare samples and, where possible, undertake microscopic examinations, during quarantine evaluation of high-risk transfers and introductions. Containers and reagents should be available to permit sample dispatch to diagnostic laboratories for examination, if necessary. Samples leaving a high-risk quarantine containment facility should be delivered by approved quarantine personnel or be preserved and secured for handling by nonquarantine personnel (such as clear handling and delivery instructions, sealed waterproof containers, documentation, etc.).

Disease Diagnosis and Health Examinations

Gross examination for evidence of disease is a minimum requirement for quarantine measures. Personnel can readily undertake microscopic examination for surface parasites as long as they have basic training in fish health and access to dissecting equipment and compound microscopes. Such training should include recognition of the broad taxonomic groups of protistan and metazoan parasites of fish and aquatic invertebrates, as a basis for treatment.

All animals that die or appear unhealthy should be examined. Access to specialized laboratory facilities, and/or personnel with experience in fish and shellfish diseases, is necessary if disease problems cannot be resolved within the quarantine facility.

Examination of healthy animals may be required in order to screen for sub-clinical infections. This is the case for introductions or transfers that have been assessed as being of high or unknown health risk. One such examination should be conducted pre-transfer and at least one other examination made post-transfer. The number of animals sampled should be in accordance with standard sampling procedures. This typically requires the use of specific diagnostic procedures and tests, and the use of quarantine containment laboratory facilities.

Freedom from specific diseases

A checklist of diseases and parasites known to affect the candidate species should be used as the basis for health certification of freedom from such diseases.

Treatment

Many diseases, especially the common diseases caused by external parasites, can be treated with readily available treatments (for example salt baths, fresh water, formalin). Other registered treatments may be available, but might require veterinary prescription or administration. Many organisms, especially internal agents, cannot readily be treated. It should be noted that the misuse of chemical treatment may cause additional health complications, such as the development of antibiotic-resistant strains of bacteria. Chemical therapy should, therefore, be used with due caution and expert advice. Wild stocks are particularly susceptible to outbreaks of external parasites. This can be prevented by an initial treatment of animals entering a quarantine facility or by careful monitoring and husbandry modification (for example temperature reduction, decreased feeding regime or holding density).

Institutional Development and Capacity Building Requirements Legislative Frameworks

There are varying degrees of aquatic animal quarantine or health-related regulations to be found in the African region, ranging from the total absence to strict regulation, based on precise legislation. In general terms, a legal framework concerning the health management procedure is essential to the implementation of an effective program to reduce the risk of trans-boundary movement of aquatic animal pathogens.

In all cases, legislation for the import and export of live aquatic animals tends to be more comprehensive than that for the within-country movement of aquatic animals. Equally, more precise legislation dealing with the importation of live aquatic animals was reported in comparison to that dealing with their exportation. In terms of health, export regulations are governed predominantly by importing country requirements.

Resources

The resources that are needed for aquatic animal disease control take many forms, and will require access to institutional, laboratory, and human resources.

Institutional Resources

Institutional resources comprise both those organizations responsible for policy development, and those applying and enforcing regulations. The country strategies indicate a range of existing governmental infrastructure in terms of aquatic animal trade and production. Institutions, other than those holding direct legislative responsibility for aquatic animal health and live animal movement involved in this area, include government and semi-government research organizations, universities, international research institutes, extension services, and private sector companies with diagnostic capability.

Laboratory Resources

The diagnostic laboratory resources range from those whose primary purpose is non-diagnostic (for example general bacteriology or water quality laboratories) through general veterinary facilities to laboratories specializing in aquatic animal disease diagnosis for fisheries and/or aquaculture. Diagnostic capability in many of the participating countries was reported to be deficient, from Level I to Level III capacity. Enhancement of laboratory facilities and increased training are frequently identified within national strategies as areas for improvement.

Human Resources

The level of human resources involved in aquatic animal disease control, measured both as the number of staff and as the level of expertise and formal qualifications held by individuals, vary greatly among countries. Human resources development at all levels from the farmer to the level of the policy-maker will be essential to support the implementation of disease control programs. The range of expert disciplines includes veterinary science, virology, bacteriology and mycology, parasitology, water and soil chemistry and specific aquatic animal health and pathology expertise. The qualifications of staff include: doctoral (Ph.D.), master's (M.Sc.), and bachelor's (B.Sc.) degrees in biological sciences; veterinary science degrees (D.V.M.), and other technical qualifications. Many countries in Africa lack aquatic animal health expertise and call for greater support in training. Training at all levels must take account of the educational level and language skills of the participants. The quality of training should be monitored to ensure effectiveness. This is particularly critical at the extension and farm levels, where many people must be trained and the educational levels may be lower. This is also the first and most important level of reporting and information gathering. In general terms, considerable capacity building in terms of knowledge and skills is required at this level the pond level among farmers and local (government and non-government) institutions involved in working directly with farmers.

Training at the satellite, national and regional laboratory levels must ensure accuracy and standardization if it is to fulfill both the needs of farmers and of an internationally recognized reporting system. Standardization of approaches will benefit from better national and regional cooperation in human resources development. In researchers, the capacity to carry out problem-solving research must be available. This research must be demand-led and serve the end user. Research products must be delivered in a timely manner, and in a form that serves both the research and farming communities. In this way, both national and regional needs will be served. Technical and other support staff must be trained in order to relieve researchers and diagnosticians of the burden of routine work and to ensure that this work is handled rapidly.

Training and infrastructure development should be clearly matched against requirements (for example potential pathogen risks, economic importance). Many of the least costly activities are ultimately the most important and are likely to generate the greatest benefits, as disease awareness and reporting begins at the pond side. Analysis of cost-benefits from investments in infrastructure and training should be considered at an early stage in the development of national strategies.

There are considerable opportunities for regional-level training, particularly in those areas where advanced skills are scarce or not yet available. This may include training in such fields as epidemiology, histopathological diagnosis, immunology and molecular biology, virology, extension methodology in aquatic animal health, mycology, research methodology and design, and risk analysis and management.

Training should be matched against the health management procedures. Examples of knowledge and skills required for selected health management procedures are provided in Table 1. A rational approach to staff development requires national institutions to develop a policy that identifies their requirements and focuses on areas of need, identifying appropriate staff, and providing them with the training and resources needed to develop facilities and services.

Financial Resources

There are significant differences among African countries in the budgetary allocation to aquatic animal health control. Some governments have injected considerable funds into aquatic animal

Table 1. Examples of knowledge and skills required for selected health management procedures.

Level	Site	Acitvity	Requirement
I	Field	Observation of animal and the environment Clinical examination	Investment in training, access to information – little or no equipment required. (Site access may require boat or negotiation of cooperation with culture-site managers and employees). Investment in training and basic equipment; access to information required.
II	Lab	Parasitology Bacteriology Mycology Histopathology	Significant investment in training, equipment and running costs. Access to current information required.
III	Lab	Virology Electron microscopy Molecular biology Immunology	Considerable investment in training and equipment and considerable running costs. Access to current information required.

health in response to the devastating impact of disease on aquaculture and fisheries in the region. Others have no specific funding earmarked for aquatic animal health-related activities, although some work is performed using general budgetary allocations for agriculture and fisheries activities.

Harmonization with International Standards

International harmonization of aquatic animal health measures is becoming increasingly important, and all member countries should tailor development of aquatic animal health strategies to be consistent with their international trade and other obligations, such as the WTO's Agreement on the Application of Sanitary and Phytosanitary Measures.

Conclusion

The advent of serious disease incidents in both aquaculture and fisheries in the Asian and Latin American regions over the past decade has resulted in a greater emphasis on aquatic animal health all over the world. In response, there has been the development of improved legislative frameworks, diagnostic facilities and expertise, and an increased commitment to the goals of sustainability and minimizing ecological impacts. However, it is clear that much remains to be done. Greater resources coupled with increased cooperation among countries, and a degree of harmonization of aquatic animal disease control policies and measures will facilitate meeting this goal.

The following are three specific areas that countries in the African region should consider when developing aquatic animal health strategies:

- Jurisdictional clarity;
- Consistency with international standards and obligations; and
- Greater participation of the private sector in policy making and providing financial resources.

Consistency between terrestrial and aquatic animal systems will provide increased efficiency and a larger workforce of trained staff at times of peak demand, as well as facilitate meeting international obligations.

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Protocols for Moving Germplasm among Countries in Africa

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Abstract

The paper briefly describes the international protocols, codes of practice, and guidelines that have been developed to control the introduction of alien species, with particular reference to genetically modified aquatic organisms. The effectiveness of implementation of these instruments/regulatory measures in southern African countries, with focus on South Africa, is also discussed. Majority of the guidelines and international protocols relating to movement of aquatic alien species and to which the southern African countries are a party have not been followed. Practical measures to address the constraints in implementation of the regulatory measures/national legislations in Africa are suggested.

Introduction

The term "germplasm" is an old word referring to a theory proposed by Weismann in 1886 concerning a "particular kind of protoplasm" found in germ-cells. In the modern context, however, the term is equivalent to "genetic material", and such material can be transported in a variety of ways including the following:

(i) within the cells of living, functioning organisms;
(ii) within *in vitro* tissue cultures; and
(iii) within "carriers" such as bacterial or viral cells, or in special solutions at low temperatures where DNA, or portions of DNA, may be transported.

It should be noted that protocols and legislation relating to introductions of genetically modified organisms (GMOs) are concerned with the introduction of the actual organisms (as in (i) above) and/or tissue cultures (as in (ii) above), but not with the transfer of genetic material as described in (iii) above, over which there are very few international regulations (Kirby personal communication).

Living organisms, as defined in (i) above, include dormant stages of life cycles (for example, seeds, eggs, pupae). Although the relevant protocols that have been developed to control the spread of organisms beyond their native ranges generally deal with both plants and animals, the focus of this paper is on aquatic animals.

The issue of controlling the movement of GMOs between countries appears to be a new one. When this is seen within the whole context of the introduction of alien species into regions beyond their native ranges, however, it soon becomes clear that a GMO can be regarded as a special type of "alien species", and this is how it is dealt with in this paper. One of the chief concerns relating to such introductions revolves around the threat of genetic contamination of indigenous stocks as a result of mating between the imported species or GMOs and indigenous species. The protocols and codes of practice that deal with the movement of GMOs are not usually fundamentally different to those previously in place for the control of importation of alien species, and are often found as a sub-set or addendum to previously-developed protocols. Legislation, as opposed to protocols and codes, that deal with importation of GMOs, however, is often different to that covering the introduction of alien species. Most of the legislation on the release of GMOs into the environment deals mainly with plant material, and does not relate specifically to alien aquatic species.

This paper focuses on international protocols, codes of practice, and guidelines that have been developed to control the introductions of alien species into new regions, particularly those protocols that relate specifically to GMOs

[1] The views of the author, as expressed in this publication, do not necessarily reflect those of the SAIAB.

or include clauses that relate to GMOs. The effectiveness of the implementation of these measures in southern African countries (with particular emphasis on South Africa) is also examined.

Definitions of Terms

Genetically Modified Organisms (GMOs) (Also referred to as living modified organisms or LMOs). There are a number of definitions of GMOs, but for the purpose of this paper the definition proposed by the European Union (CEC 1990) has been adopted: "A GMO is an organism in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination." This definition excludes the products of selective breeding and organisms that have had their chromosome set altered (e.g., Polyploidy).

Alien species. (IUCN definition = non-native, non-indigenous, foreign, exotic): A species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e., outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gametes, or propagule of such species that might survive and subsequently reproduce.

Established species. (= naturalized species): An introduced species that has established self-sustaining populations in natural or semi-natural habitats. This excludes species that are only found in captivity in artificial environments. In many protocols such as the ICES/EIFAC Code of Practice (Turner 1988; ICES 1995), the assumption is made that all species kept in artificial environments, such as aquaculture facilities, will at some stage have the opportunity to escape into natural habitats, where they may or may not be able to establish self-sustaining populations.

Protocols and Codes of Practice to Regulate the Introduction of Alien Species and GMOs into New Regions

A number of codes of practice and protocols have been developed to deal with the issue of alien species and many of these protocols, for example, the Food and Agricultural Organisation (FAO) Code of Conduct for Responsible Fisheries (CCRF) (FAO 1995) and the ICES/EIFAC Codes of Practice (Turner 1988; ICES 1995) have been modified to include sections on the transfer of GMOs. The Cartagena Protocol, however, deals more specifically with GMOs. The FAO and other international bodies have also developed a number of technical guidelines that assist in the implementation of the protocols. A summary of the more widely accepted international protocols, codes of practice and technical guidelines is outlined in Table 1.

Most international conventions and proposed codes of practice usually have limited legal status within the signatory countries. They are not regulations, but voluntary systems that can be adopted to address particular problems.

Common themes and principles espoused in many International Codes of Practice relating to the importation of alien species

* Emphasis on the enactment of suitable recommendations on the setting up of appropriate agencies for the application and enforcement of such legislation. In this respect it is recommended in the IUCN guidelines (website on the Species Survival Commission) that countries should "ensure, wherever possible, the designation of a single authority or agency responsible for the implementation and enforcement of national legislation, with clear powers and functions. In cases where this proves impossible, ensure there is a mechanism to coordinate administrative action in this field, and set up clear powers and responsibilities between the administrators concerned."

* Emphasis on the importance of setting up a decision-support system, such as the protocols set up by EIFAC/ICES (Turner 1988), to assist legislators in making informed decisions.

* Since control or eradication of alien species is extremely difficult once populations have been established in natural waters, the emphasis is on prevention of further importations rather than eradication of established populations. The greatest focus is, therefore, on the control of importations of species into countries.

* Unintentional introductions often involve parasites and the importation of species via

Table 1. Instruments relating to the transfer of alien species and/or GMOs into new regions.

Instrument	Area of emphasis	Comments	References
FAO Code of Conduct for Responsible Fisheries (CCRF)	Sustainable use and conservation of living aquatic resources.	Voluntary code on general issues of responsible fisheries.	Bartley 1998 FAO 1995
ICES/EIFAC Code of Practice on the introduction and transfer of marine organisms	Purposeful introduction of marine (ICES) and inland (EIFAC) species and GMOs.	General code of practice created for developed areas, but is being accepted in principle in developing areas.	Tuner1988 ICES 1995 Bartley 1998
FAO/Sweden Precautionary approach to Fisheries. F1. Technical papers 350/1 and 2.	Precautionary approach to capture fisheries and species introductions.	Defines in a rigorous manner what the precautionary approach means.	FAO 1996 Bartley 1998
Cartegena Protocol on Biosafety (linked to Convention on Biodiversity)	Seeks to protect biological diversity from potential risks posed by LMOs resulting from modern biotechnology.	Notification and assessment procedures including "advanced informed agreement" (AIA) procedure for ensuring that countries are provided with information necessary to make informed decisions before importation of the LMOs.	website*
Convention on Biodiversity	Comprehensive agreement covering many aspects of biodiversity including alien species and GMOs.	Contains biosafety control link to website. Article 8(g) deals with LMOs. Article 8(h) deals with alien species in general. Article 19 directs parties to consider the need and modalities for internationally binding protocols on the safe transfer and handling of LMOs that may have adverse effects on the conservation and sustainable use of biological diversity.	website*
IUCN Guidelines for the prevention of biodiversity loss caused by alien species	Fosters cooperation between countries and recommendations on enactment of domestic legislation.	Links to many other protocols and codes of practice.	website*
International Network on Genetics in Aquaculture (INGA)	To foster regional and international cooperation in aquaculture genetics research.	Facilitates exchange of germplasm while striving for conservation of biodiversity in developing countries.	website*
SADC Protocol on Fisheries	To prevent introduction of species or GMOs into shared aquatic ecosystems.	Ensures neighboring countries are informed of any alien species or GMO introductions.	SADC 2001

* See reference list for website addresses.

ballast water. Prevention of the importation of these species involves measures to treat ballast water, setting up various quarantine measures, and disseminating information to travelers at ports of entry into countries.

* Many agreements, such as the CCRF, make the assumption that imported species, even if kept in semi-captive situations, will have the opportunity to escape into natural waters. Introductions into aquaculture facilities are, therefore, regarded as being essentially the same as introductions into natural waters.

* Since impacts are unpredictable, intentional introductions should be based on the precautionary approach. Where information is lacking, unreliable or uncertain, caution must be exercised with regard to permitting new introductions. Other implications of the precautionary approach are not agreed upon. It may imply that, unless there is a reasonable likelihood that an introduction will be harmless, it should be treated as likely to be harmful. FAO has tried to define what this approach involves in relation to capture fisheries and species introductions (FAO 1996; Bartley and Minchin 1997). Among other things, the approach implies reversibility of impacts, the establishment of reference points and pre-agreed contingency plans.

* Invasive alien species (including GMOs) can be regarded as "biological pollution" agents. Part of the regulatory response to introductions should, therefore, be based on the principle that "the polluter pays," where "pollution" represents the damage to native biological diversity and the "polluter" represents the person or agency involved in the importation. Enforcement should involve appropriate levels of punishment for infringement, payment for initial impact assessment and payment for eradication/mitigation efforts should the alien species have harmful effects on the environment.

* Introductions should only be permitted if positive effects outweigh the actual and potential adverse effects.

* Introductions should not be permitted if experience elsewhere indicates that the probable result will be a loss in biological diversity.

Special Features of Protocols dealing with GMOs

In addition to the general principles as outlined above, protocols (or sections of protocols) that deal with the issue of GMO introductions include a number of unique features. Of particular interest is the Cartagena Protocol on Biosafety, which was adopted at the Conference of the Parties to the Convention on Biological Diversity (CBD) in Montreal in January 2000. The Protocol (which adopts the term "Living Modified Organism" in preference to GMO) establishes an Advance Informed Agreement (AIA) procedure to ensure that countries are provided with the information necessary to make informed decisions before agreeing to the import of such organisms into their territory (Bartley 1999). The Protocol also contains reference to a precautionary approach and establishes a "Biosafety Clearing-House" to facilitate the exchange of information on living modified organisms and to assist countries in the implementation of the Protocol (Bartley 1999). The aims of this Protocol are partially outlined in the following statement (extracted from Section 13):

> "The objective of this Protocol is to contribute to ensuring an adequate level of protection in the field of the safe transfer, handling and use of living modified organisms resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health, and specifically focusing on trans-boundary movements."

Important aspects of this Protocol are outlined in Text Box 1. This indicates that emphasis has been placed on proper notification, transparency, and trans-border cooperation. Of particular interest is Appendix 1 of the Protocol that outlines the detailed requirements associated with the descriptions of the donor and recipient organisms as well as the nucleic acid or other modification introduced, the technique used and the resulting characteristics of the LMO.

Translating International Agreements into Practical, Workable Policies

Information on the relevant legislation and implementation throughout Africa was not readily available. For this reason, this paper has focused on the Southern African Development Community (SADC) countries, with particular emphasis on South Africa, for which information was available.

International conventions and agreements are essentially contracts between different states and they have no legal effect domestically. They only become effective when governments pass relevant domestic legislation to bring such laws into effect. International agreements do, however, have some impact on their own: states that are signatories to such agreements do not normally openly flaunt them even if the relevant domestic legislation has not yet been enacted. They cannot, however, force their own citizens to abide by international laws until they have passed the relevant domestic legislation (Midgley, personal communication).

Putting various international protocols and agreements into effective use normally involves three phases.

Phase 1: Country becomes signatory to a particular international agreement.

Phase 2: Enactment of domestic legislation in accordance with the principles set out in the international agreement. Well-thought-out legislation will make provisions for the establishment of an appropriate enforcement agency and penalties for violations of the law.

Phase 3: Implementation and enforcement. This relates to the establishment

Text Box 1. Important clauses of the Cartegena Protocol on Biosafety.

Procedures for LMOs developed for domestic use (extract from Article 11)

1. *"A party that makes a final decision regarding domestic use, including placing on the market, of a living modified organism that may be subject to trans-boundry movement for direct use as food or feed, or for processing shall, within fifteen days of making that decision, inform the parties through the Biosafety Clearing-House."*

Risk assessment (extract from Article 15)

"A risk assessment undertaken pursuant to this Protocol shall be carried out in a scientifically sound manner, ... in order to identify and evaluate the possible adverse effects of living modified organisms on the conservation and sustainable use of biological diversity, taking also into account risks to human health."
"The party of import shall ensure that risk assessments are carried out for decisions taken under Article 10. It may require the exporter to carry out the risk assessment."
"The cost of the risk assessment shall be borne by the notifier if the party of import so requires."

Risk management (extract from Article 17)

1. *"The parties shall, taking into account Article 8 (g) of the Convention, establish and maintain appropriate mechanisms, measures and strategies to regulate, manage and control risks identified in the risk assessment provisions of this Protocol associated with the use, handling and trans-boundary movement of living modified organisms."*
2. *"Measures based on risk assessment shall be imposed to the extent necessary to prevent adverse effects of the living modified organism on the conservation and sustainable use of biological diversity, taking also into account risks to human health, within the territory of the party of import."*
3. *"Each party shall take appropriate measures to prevent unintentional trans-boundary movements of living modified organisms, including such measures as requiring a risk assessment to be carried out prior to the first release of a living modified organism."*

Unintentional trans-boundary movements and emergency measures (extract from Article 17)

1. *"Each party shall take appropriate measures to notify affected or potentially affected States, the Biosafety Clearing-House and, where appropriate, relevant international organizations, when it knows of an occurrence under its jurisdiction resulting in a release that leads, or may lead, to an unintentional trans-boundary movement of a living modified organism that is likely to have significant adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health in such States. The notification shall be provided as soon as the party knows of the above situation."*
2. *"Each party shall, no later than the date of entry into force of this Protocol for it, make available to the Biosafety Clearing-House the relevant details setting out its point of contact for the purposes of receiving notifications under this Article."*
4. *"Consultation with the affected or potentially affected States to enable them to determine appropriate responses and initiate necessary action, including emergency measures."*

Annex I outlines the information that is required in the notifications mentioned under Articles 8, 10 and 13.
Annex III (on Risk assessment) contains further details of the objectives, uses, principles and methodology associated with risk assessment.

and functioning of an appropriate management authority that will be responsible for evaluating proposed introductions. Ideally, if the FAO Code of Conduct for Responsible Fisheries is to be followed, it would also be necessary to appoint independent review panels to carry out the "review and evaluation" using an appropriate decision-support protocol as outlined in Appendix 1.

Effectiveness of enforcement is largely dependent on the quality of the original legislation and on local capacity in terms of funds and the availability of trained personnel with sufficient skills to understand and enact the law. Widespread corruption could also result in a breakdown of enforcement of the law.

Legislation may not, however, always follow the above path. Countries may enact their own legislation without reference to international agreements, or with only minor references to international agreements. They may also merely pay lip service to international agreements without actually incorporating the major aspects of the agreements into their own legislation. Domestic legislation in various countries, therefore, exhibits various degrees of compliance with the international agreements.

International and Regional Agreements to which SADC Countries are Signatories

The preamble to the SADC Protocol contains references to the FAO Code of Conduct for Responsible Fisheries (CCRF). In addition to this, all 12 member states are signatories to the Convention on Biodiversity (Davies and Wishart 2000).

Regional Agreements: The SADC Protocol on Fisheries records that "a state party shall not introduce exotic species or genetically modified species into aquatic ecosystems shared by two states including the full extent of the river basin unless the affected state parties agree to the introduction." This protocol has been signed by all member states and contains a reference to the FAO-CCRF.

Implementation of Legislation

It is beyond the scope of this paper to examine legislation in any great detail, but in order to assess problems related to implementation, it would be necessary to consider some of the relevant sections of the legislation.

As noted previously, a GMO can be regarded as a special type of alien species and the management of the introductions of GMOs is dealt with in the same international protocols or in similar protocols as those concerned with alien species as a whole. In South Africa, and probably in most other countries, the legislation concerned with the importation of GMOs is, however, different and under different jurisdiction to that controlling the importation of alien aquatic species. The reason for this relates to the fact that GMO legislation is concerned principally with agricultural crops, and is not really comparable to legislation that is concerned principally with the conservation of freshwater ecosystems. This reflects the fact that there have been very few (if any) requests for the importation of aquatic GMOs into South Africa and this is probably also the case for the rest of Africa (Kirby personal communication).

It is, however, likely that in future there will be some requests for permits for the importation of aquatic GMOs, in which case it may be necessary to adapt existing laws controlling the importation of alien aquatic species. To gain insights into the possible problems that may arise in relation to the implementation of such legislation, it is necessary to examine the way in which existing legislation is implemented.

Legislation Relating to Alien Aquatic Species

The issue of relevant national legislation and its implementation was discussed during an ALCOM meeting on the problems of alien species in the Limpopo River (van der Mheen 1997). A number of nature conservation officials from the four SADC countries that border the Limpopo River (Mozambique, South Africa, Swaziland, and Zimbabwe) participated in the meeting. Information from van der Mheen (1997) has been summarized in Table 2.

Implementation of laws relating to nature conservation in South Africa is in a state of flux, partly because of the upheavals that followed the reorganization of provincial administration subsequent to changes to the constitution in the 1990s, which has seen the creation of nine provincial authorities from the previous four.

Legislation Relating to GMOs

The only information on legislation that could be obtained relates to legislation in South Africa embodied in the Genetically Modified Organisms Act of 1997. Some sections of this legislation are in Text Box 2. The Act makes clear recommendations concerning the application of the Act and contains many items that deal with the implementation of the Act. There is a great deal of emphasis on transparency, particularly relating to the notification of intention to release GMOs.

Implementation in relation to Alien Aquatic Species

In order to illustrate some of the problems that have been experienced in relation to the enforcement and application of the law, it is worth examining the experiences of nature conservation officials as well as case histories of certain events surrounding the importation of some "controversial" species into southern Africa. Information on the application and implementation of the law is based on the direct experiences of the author as well as through personal communications with the officials in provincial nature conservation departments in South Africa.

Authority relating to the issuing of permits rests with provincial conservation departments, but is ultimately under the authority of the Department of Plant and Quality Control (within the Department of Agriculture) which normally provides some policy guidelines to provincial conservation departments. The situation regarding the control of the provincial nature conservation Departments is, however, extremely complex. At a national level these departments fall under the Department of Environment Affairs and Tourism, but at a provincial level, they are aligned to a variety of different provincial departments. Although provincial authorities issue permits,

Table 2. Legislation/regulations in certain SADC countries that border the Limpopo River that contain clauses of some relevance to the importation of alien species, as well as extracts from the relevant legislation and the government departments responsible for administering such legislation[1].

Country	Relevant government departments (main department that controls importation of alien species and subsidiary departments).	Relevant legislation/regulations/policies and relevant sections of acts.
Botswana	Main department: Ministry of Agriculture. Subsidiary departments: Department of Water Affairs (Ministry of Public Works and Housing); Ministry of Commerce and Industry.	Fish Protection Act: "The Minister may make regulations which shall apply to such areas as are specified therein, providing for the more effectual control, protection and improvement of fish, and the government and management of any specified area in which fishing may be carried on, and without prejudice to the generality of the foregoing for all or any part of the following purposes … (g) prohibiting, restricting or regulating the bringing into Botswana of live fish; (h) prohibiting, restricting or regulating the transfer within Botswana of any live fish."
Mozambique	Main department: Department of Water Affairs (Ministry of Public Works and Housing). Subsidiary department: Ministry of Agriculture and Fisheries. Related instruments/committees: National Water Council.	National Water Policy, but no clear legislation specifically on alien introductions. Present legislation (from 1960) states:" The Secretary of State for Fisheries, in co-ordination with the Ministry of Agriculture, should determine necessary measures for the development of agriculture, namely: (b) rules required for the introduction of new species.The Secretary of State for Fisheries can define measures to conserve the fisheries resources, namely: (c) adopt any conservation measures necessary for the preservation of fish resources."
South Africa	Department of Water Affairs and Forestry and subsidiary Institutes (such as Institute for Water Quality Studies); Department of Agriculture and subsidiaries (Department of Plant and Quality Control); Provincial Departments of Nature Conservation (subsidiary to Department of Environment Affairs and Tourism, but under control of a number of different departments in different provinces). Important Committees/Programs: NACC[2] and NAEBP[3].	Department of Plant and Quality Control (subsidiary of Department of Agriculture) responsible for issuing permits for importation of alien species. Provincial Department of Nature Conservation responsible for application and enforcement of law. Legislation complex and presently in a state of flux, but government produced a white paper on "The Conservation and Sustainable use of South Africa's Biological Diversity"[4] that contains clauses relating to the importation of alien species. It is expected that improved legislation will follow from this document. The NACC has produced prohibited and approved lists of alien species for importation and a number of guidelines have been developed concerning stocking of particular groups of alien aquatic species (for example bass, trout, carp and other species). NACC has, however, now been disbanded (see comment in main text of this paper).
Zimbabwe	Main department: Department of National Parks and Wildlife Management (Ministry of Environment and Tourism). Subsidiary departments: Department of Water Resources (Ministry of Energy and Water Resources Development); Department of Natural Resources (Ministry of Environment and Tourism)	Introduction and transfer of fish (National Parks & Wildlife Act of 1975):"No person shall (a) without reasonable excuse, the proof whereof lies on him, introduce into any waters any species of fish or any aquatic plant which is not native to such water or (b) import any live fish or ova of any fish except in terms of a permit issued in terms of Section 83."

[1] (from van der Mheen. 1997 and Angliss, Coke, Engelbrecht, Impson and Kruger personal communication).
[2] NACC - National Aquatic Conservation Committee.
[3] NAEBP - National Aquatic Ecosystem Biomonitoring Program
[4] See comment elsewhere (in Text Box 2) and the relevant sections of this white paper.

they normally receive policy guidelines from the central authority.

The National Aquatic Conservation Committee (NACC) comprising of representatives from all provincial conservation departments was initiated in 1995 with the objective to provide policy guidelines, particularly with regard to the granting of permits. This resulted in the compilation of Prohibited and Approved Lists (which related mainly to ornamental species and aquaculture species). Policy guidelines were also developed concerning the stocking of certain groups of fish (for example grass carp) in natural waters. This was an ad hoc committee that did not make use of any protocols or codes of practice,

Text Box 2. Features of the South African Genetically Modified Organisms Act that deals with implementation of the law.

The following items of this Act have specific recommendations concerning application of the law (only headings and brief description given below):

3. Setting up an Executive Council of Genetically Modified Organisms.
4. Objectives of the Council.
5. Powers and duties of the Council. This section outlines the procedure involved in applications for permits, assessment of permits, registration of the application, decision process by the committee, and conditions of notification (ensuring some degree of transparency relating to the decisions of the committee).
7. Meetings of the Council (Item 7) outlining times when meetings should be called.
8. Appointment of a registrar (Item 8) that is charged with the administration of the Act.
9. Functions of the registrar (Item 9).
10. Setting up an advisory Committee "which shall consist of not more than ten persons appointed by the Minister after the recommendation of the council... of whom –
    (a) not more than eight members shall be knowledgeable persons in those fields of science applicable to the development and release of genetically modified organisms;
    (b) two persons shall be from the public sector and shall have knowledge of ecological matters and genetically modified organisms."
11. Functions of the Committee.
12. Funding.
13. Conflict of Interest.
14. Prohibition of Activities concerning genetically modified organisms.
15. Inspectors.
16. Routine inspections by inspectors.
17. Determination of risks and liability.
18. Confidentiality.
19. Appeals.
20. Regulations.

but drew on the expertise of various academics and conservation personnel.

In 1998 NACC meetings and consequently the committee was disbanded (Coke, personal communication) as the provincial departments could no longer afford to pay for the costs of attendance. The feeling amongst the nature conservation officials is that the NACC served an important function and that there is a great need for policy guidance from the central government. In spite of this, some of the officials felt that the law was functioning reasonably well, but felt that there was room for improvement.

Case History: Alien Freshwater Crayfish in Southern Africa

There has been considerable pressure from various aquaculturists to permit the importation of various species of freshwater crayfish into southern Africa. During the early 1990s, permits were granted to allow the importation of certain species of *Cherax* into the former Orange Free State Province (OFS). Following a consultancy to examine the potential impact of these species on natural waters (de Moor and James 1993), the former Transvaal Province prohibited the importation of such species. The OFS then attempted to revise the conditions under which the crayfish were to be kept in captivity in the aquaculture facility where they had been permitted. This caused a great deal of controversy amongst aquaculturists, particularly from the person who had been granted the permit to import the crayfish into the OFS. Following this controversy, the Department of Agriculture commissioned a second, more comprehensive, literature review on the potential impact of a number of alien species of crayfish (*Cherax tenuimanus*, *C. quadricarinatus*, *C. albidus*, *C. destructor*, *C. esculus* and *Procambarus clarkii*) (de Moor and Holden 1997). The applicant for the permit was responsible for paying for the first evaluation whereas the Department of Agriculture was responsible for the second.

Since 1997, there have been numerous requests from various aquaculturists for permits to import alien crayfish, particularly *C. quadricarinatus*. The Department of Agriculture has, however, kept the report of de Moor and Holden confidential and has not issued any policy guidelines to provincial nature conservation departments regarding the importation of these species. (Note that, with the exception of *C. tenuimanus*, the importation of all these species was previously not allowed). In the absence of any further directives from central government, most provincial departments have, based on their own information-gathering processes, decided not to allow the importation of this species. The lack of coherence in policy and the confidentiality surrounding the de Moor and Holden report has, however, raised protests from conservation-related NGOs, such as the Wildlife and Environment Society of South Africa (Rogers 2000; Cooper personal communication) that are opposed to the introduction of alien freshwater crayfish, as well as from a group of freshwater ecologists who voiced their opposition to the importations (Cambray et al. 1999).

During the 1990s, an import permit for the cultivation of *C. quadricarinatus* was, however, granted by the Swaziland government and an aquaculture facility was set up near the Sand River Dam (Komati River, Crocodile tributary of the Nkomati System) very close to the Mpumalanga border. In spite of the fact that this species was still prohibited in all South African provinces, culture of this species was promoted by the importer (Copeland 1999). Subsequently the importer has abandoned his aquaculture farm in Swaziland and crayfish have escaped into the Sand River dam where they are reported to be spreading into neighboring irrigation canals (Engelbrecht personal communication). There are also unconfirmed reports that another species of freshwater crayfish (*Procambarus clarkii*) that is also banned in South Africa has also been found in the region, and it is suspected that this may have escaped from one of the aquaculture farms. It is not certain whether the aquaculturist had a valid permit to keep *P. clarkii* in Swaziland.

In relation to the above, it is clear that many of the guidelines and international protocols (such as the CCRF) to which SADC countries are a party, have not been followed, and it is worth noting the following aspects of this case study:

- Transvaal Department of Nature Conservation had intended to adopt the "polluter pays" principle, but there are problems in implementation, particularly in cases where the "polluter" has to pay consultants directly. There is clearly a need for a central agency to manage funds (as is the case for the implementation of GMO-related legislation described below).
- The lack of transparency in relation to the publication of a report (de Moor and Holden 1997) that was commissioned by a government department and paid for with public funds. Applicants for importation permits have complained of the lack of transparency as reasons why permits are not usually given (Kirby personal communication).
- Evaluation process was not followed up by a decision-making process (as recommended in the CCRF, espoused in the SADC Protocol on Fisheries).
- Lack of coherence in relation to implementation between different provinces within South Africa (the former Transvaal and Orange Free State) and between neighboring states (South Africa and Swaziland).
- Lack of policy guidelines from a central authority regarding the granting of permits.
- Lack of notification, particularly between different countries despite the fact that this species was prohibited in South Africa and was placed in a communal watercourse close to the borders of the two countries.
- Lack of coherence between different sectors of the scientific community. An alien species that was prohibited for importation was actively promoted as a "desirable" species at an aquaculture conference.

An examination (Table 2), suggests that in the four SADC countries bordering the Limpopo River, the issuing of permits for the importation of alien species does not follow any specific protocols and is probably done on an *ad hoc* basis, at the discretion of the minister (who is advised by various experts).

Implementation in Relation to GMOs

Unlike the legislation relating to the importation of alien aquatic species (Table 2), the legislation relating to the importation of GMOs in South Africa has a number of specific directions regarding the application of the law (see Text Box 2):

- assigning a "registrar" who is charged with the administration of the Act;
- setting up of an advisory committee, including directions concerning the composition of such a committee; and
- high degree of transparency regarding notification of intention to release a GMO.

In many ways the implementation of the GMO legislation functions well, particularly in relation to the following aspects (Prof. Kirby personal communication):

- payment for evaluation is borne by the applicants via a fee that is paid to the registrar who then administers the evaluation process; and

- the registrar appoints various people (particularly those on the advisory committee) to assist in assessing the evaluations submitted.

Costs are kept at a minimum with evaluation being largely carried out by the advisory committee that is paid a fee by the registrar. However, there has been some criticism regarding the implementation of the law. Procedures relating to notification were not carried out strictly in accordance with the law and it was felt that there should have been a greater degree of transparency.

Conclusion

From the above description it is clear that many of the important principles outlined in protocols (such as the Cartagena Protocol) on GMOs have already been incorporated into South African legislation. Of particular importance is the functioning of the central registrar and the advisory committee, a feature relating to implementation that was written into the initial legislation. Unfortunately, this is not the case regarding legislation and implementation relating to importations of alien aquatic species.

The South African government has, however, recently published a White Paper on the conservation and sustainable use of biological diversity (1997) that contains a section on the importation of alien aquatic animals (see Text Box 3). The intention to improve legislation relating to alien species is embodied in the following statement:

"Government recognises that many past efforts at control have been unsuccessful, a major problem being the fact that responses have been reactive, with actions taken only after invasive alien species have become a problem. This ad hoc approach has not been cost-effective, and has resulted in drastic impacts on biodiversity. To redress this, Government will adopt a proactive, preventative and precautionary approach to control the introduction and spread of alien organisms."

Work is currently underway on the development of a new bill on biodiversity in South Africa and it is hoped that many of the principles outlined in some of the international protocols (such as the EIFAC Code of Practice and the CCRF) that are espoused in the South African White Paper, will find their way into this legislation and into its implementation. Although time constraints did not permit a detailed examination of the implementation of the law in other African countries, a brief description of the relevant legislation (van der Mheen 1997 and summarized in Table 2) suggests that, at least in the four SADC countries bordering the Limpopo River, legislation and implementation of legislation relating to alien aquatic species fall short of many of the recommendations outlined in international protocols such as the CCRF.

Recommendations

Many of the problems surrounding implementation of the law arise from a lack of capacity (in terms of funds and trained personnel) as well as inadequate legislation and a lack of clarity on the part of governments concerning the implementation of legislation. In order to overcome some of these problems, it is recommended that the following initial actions be taken:

1 That principles espoused in most protocols on the importations of alien species be enacted in domestic legislation in African countries.

2 That such legislation contain clauses outlining the setting up and functioning of appropriate implementing agencies (such as the "registrar" that is responsible for the implementation of the GMOs Act in South Africa).

3 In addition to the above implementing agency, it is also desirable to set up an advisory committee comprising some government enforcement agents (such as nature conservation officers) as well as outside experts (for example academics from local universities and other research institutions). This committee would be responsible for assessing evaluations submitted by independent consultants, conducting evaluations, or appointing independent consultants to carry out such evaluations. Such an advisory committee would also be responsible for alterations to lists of prohibited and approved species.

Consideration should also be given to setting up procedures and protocols that are relatively simple to use and cost effective. In this respect, the following recommendations are made:

1 Protocols should be simple, and consideration be given to the EIFAC/ICES Code of Practice (as outlined in Appendix 1) and adapted to the needs of the particular country concerned.

2 Steps should be taken to streamline implementation of the law and reduce costs. Practical measures include the following:

   i. That the implementing agency charges a fee from all applicants to assist with administration costs.

   ii. That the "polluter pays" principle be adopted (i.e., potential importers pay costs for consultancies). The implementing agency collects payment from the "importer" and oversees the appointment and payment of independent consultants to conduct special evaluations.

   iii. In less complicated cases, it may be possible to ask members of the advisory board to be responsible for evaluations, for which they would be paid a small fee.

   iv. Funding for the advisory committee should be made available through central government agencies rather than provincial government agencies that are often short

Text Box 3. South Africa's white paper on the conservation and sustainable use of biological diversity (1997).

Section dealing with policy strategy with regard to alien species in general.

"The *Government will adopt a proactive, preventative and precautionary approach to control the introduction and spread of alien organisms. This approach will take into consideration the need to balance the risks associated with introducing and releasing alien organisms with the potential social, economic and environmental benefits derived therefrom.*

To achieve this objective, the Government, in collaboration with interested and affected parties, will:

- *(a) Review, streamline and, if necessary, strengthen existing legislation to control the introduction and spread of potentially harmful alien organisms. Actions will be taken to improve the effectiveness of legislation and ensure consistency; and*

  (b) Strengthen the enforcement and effectiveness of existing punitive measures to control the introduction and spread of potentially harmful alien organisms.
- *Develop a regulatory procedure for the introduction of alien organisms into South Africa, whereby the potential risks of introduction are comprehensively assessed against intended benefits prior to introduction. This assessment will be followed by the adoption of appropriate mitigatory or preventative measures.*
- *Develop control and eradication programs, and provide ongoing support to existing programs, based on a priority-rating system and in relation to costs and resources. This will consider threats posed to biodiversity, as well as social, economic, and environmental costs and benefits derived from using and removing identified organisms. The planning of intensive mechanical clearing operations will take account of job creation schemes and will provide for regular follow-up.*
- *Prevent wherever feasible the unintentional introduction of alien organisms to South Africa.*
- *Develop a national policy on the inter and intra-provincial translocation and inter-basin transfer of species, including the updating of lists of prohibited and approved taxa.*
- *Promote the use of local, indigenous species in the rehabilitation and revegetation schemes.*
- *Provide incentives to landowners to control or eradicate alien organisms identified as threatening biodiversity.*
- *Strengthen, support and coordinate the efforts of existing institutions and programs to detect the early establishment of invasive alien organisms, and to catalogue and describe such invasions.*
- *Support and strengthen the development of biological and other control methods for alien organisms that threaten biodiversity.*
- *Improve understanding concerning the impacts of alien organisms on biodiversity.*
- *Improve public education and awareness concerning the risks posed by the planting or illegal importation of alien species, and identify actions that can be taken to avoid such risks or to control the spread of alien organisms.*
- *Improve capacity amongst implementing agencies to regulate the introduction, control and eradication of alien organisms that threaten biodiversity.*
- *Negotiate and liaise with neighboring countries to maximize commonalities and minimize conflicts between policies, legislation, and practices relating to alien organisms that threaten biodiversity."*

of funding. It may also be desirable to seek international funds to assist in the functioning of such advisory committees.

v. Use should be made of expertise available through international organizations as well as the websites of organisations, for example the FAO, SCOPE, INGA, the IUCN Invasive Species Specialist Group (ISSG), the Species Survival Commission (SSC), and the Database of Introductions of Aquatic Species (DIAS).

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   b. Objectives of INGA:
      http://www.worldfishcenter.org/inga/objectives.html
   c. Germplasm exchange:
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Appendix 1: The EIFAC/ICES Code of Practice

Bartley and Coates (1997) and Coates and Bartley (1997) have recommended that a modified version of the code of practice initially developed by ICES/EIFAC (Turner 1988) be applicable to the African region. This paper, therefore, focuses on elements of this Code of Practice as well as the Cartagena Protocol on Biosafety (which forms part of the Convention on Biological Diversity), which has been developed for GMOs.

The ICES/EIFAC Code of Practice

In its simplified form, the code proposes that the following steps be taken in order to arrive at an informed decision regarding the importation of alien species into the country. (Note that the assumption is made that species kept in semi-captivity will, sometime in the future, have the opportunity to escape into natural waters, so such importations are treated in the same way as deliberate introductions into natural waters.)

Step 1: Proposal to introduce or transfer species into new regions beyond its native range.
Step 2: Evaluation: in-depth risk/benefit analysis in ecological, genetic and socio-economic terms and proposed quarantine arrangements.
Step 3: Independent Review: review of proposal and evaluation, checking its thoroughness, accuracy, advising on the appropriateness of the proposal and making recommendations as to how to proceed.
Step 4: Decision by the appropriate decision-making authority on whether to proceed with the introduction. This authority should also specify quarantine conditions and any other conditions (such as regions where introductions are allowed) under which the species may be held.

(Note that the above description has been considerably simplified from the original recommendations as outlined in Turner (1988) which should be consulted for a more detailed account of these procedures. Of particular importance are the recommended regulations, especially regarding quarantine conditions, associated with the final importation of the species into the country.)

Bartley and Coates (1997) and Coates and Bartley (1997) noted the following practical issues that are essential for the proper functioning of the above procedures.

Administrative infrastructure: This is necessary for the control and management of introductions as well as the evaluation process. Penalties for defaults under legislation should also be commensurate with the degree of economic and environmental damage that inappropriate or unapproved introductions can cause. In addition to the existence of a controlling body operated by a government department, it will also be necessary to set up a review board as described in the next paragraph.

The review process: It is essential that an independent review of the proposal and its evaluation are made. It is best that the membership of the review panel should not include any person with a direct interest in the outcome of the proposal. A review panel might include, but not necessarily be limited to, the following individuals/interest groups:

- Fisheries and aquaculture specialists that also have some expertise in aquatic ecology;
- Aquatic ecologists;
- Socio-economists with experience in the aquatic sector (fisheries and/or aquaculture) and more broad socio-economic experience;
- Fisheries/aquaculture geneticists;
- Representation from the environment/ conservation sector; and
- Representation from the human health sector.

Decision-support systems: Various decision-support systems can be used to assist the review panel to come to an informed decision. Kohler and Stanley (1984) developed a review and decision model in which the panel of experts is required to address a series of questions in relation to the proposed introduction. The model is composed of five levels of review: decisions on whether to accept or reject the proposal are made at each level. The graded nature of the process means that proposals can be rejected at an early stage of the process. This streamlines the process and circumvents the necessity of having to go through the whole procedure for organisms that do not "pass" the lower levels of review.

The decision model can also make use of an opinionaire (Text Box A1) that incorporates a scoring system into the questions asked during the review process. This facilitates the process and helps the panel to arrive at a consensus decision (Text Box A2).

Text Box A1. Opinionaire* for appraisal of introductions of aquatic organisms.

Questions	Response					
	No	Unlikely	Possibly	Probably	Yes	Don't Know
1. Is the need for introduction valid, and are there no native species that could serve the stated need?	1	2	3	4	5	X
2. Is the organism safe from over-exploitation in its native range?	1	2	3	4	5	X
3. Are safeguards adequate to guard against importation of disease/parasites?	1	2	3	4	5	X
4. Would the introduction be limited to closed systems?	1	2	3	4	5	X
5. Would the organism be unable to establish a self-sustaining population in the range of habitats that would be available?	1	2	3	4	5	X
6. Would the organism have mostly positive ecological impacts?	1	2	3	4	5	X
7. Would most consequences of the introduction be beneficial to humans?	1	2	3	4	5	X
8. Is the database adequate to develop a complete species synopsis?	1	2	3	4	5	X
9. Does the database indicate desirability for introduction?	1	2	3	4	5	X
10. Based on all available information, do the benefits of the introduction outweigh the risks?	1	2	3	4	5	X

* Each member of an evaluation board or panel of experts circles the number most nearly matching his/her opinion about the probability for the occurrence of the event. If information is unavailable or uncertain then "don't know" is marked. Mean values obtained from the responses of the panel are used to come to a consensus decision in the Kohler and Stanley (1984). Review and decision model reproduced in Text Box A2.

Text Box A2. Review and decision model for evaluating proposed introductions of aquatic organisms (simplified from the Kohler and Stanley 1984 model by B. Steinmetz — as quoted in Turner 1988).

Review Level	Opinion Mean Value**	Decision
Review level I 1. Is the need for importation valid*	# 2 > 2	- reject - to next question
2. Is the organism safe from over-exploitation in its native range?	# 2 > 2	- reject - to next question
3. Are safeguards adequate to guard against the importation of disease/parasites?	# 2 > 2	- reject - to next question
4. Would the introduction be limited to a closed system?	∃ 3 > 3	- approve - to review level II
Review level II 5. Would the organism be unable to establish a self-sustaining population in the range of habitats that would be available?	∃ 3 > 3	- approve - to review level III
Review level III 6. Would the organism have mostly positive ecological impacts?	# 2 > 3 ∃ 3	- reject - to review level IV - to next question
7. Would most consequences of the introduction be beneficial to humans	# 2 > 3 ∃ 3	- reject - to review level IV - approve

continue >

> continued

Review level IV 8. Are data adequate to develop complete species synopsis?	> 3 ∃ 3	- conduct detailed literature review - to next question
9. Does the database indicate desirability of introduction?	# 2 > 3 ∃ 3	- reject - conduct research - approve
10. Would benefits exceed risks?	# 2 ∃ 3	- reject - approve

* The importation is not considered to be valid if an indigenous species could better fulfill the purpose for which the species is to be imported. The proposed importation should adequately fulfill the need for which it is to be imported. (For example, if the aquaculture potential of the candidate species is less than very good, then it would not adequately fulfill the need if it was being imported for the purpose of aquaculture.)

** Mean of values obtained for each question, based on answers given by the review panel (as detailed in Text Box A1).

Summary of Discussions and Recommendations from The Workshop

The consultation was divided into four main sessions in which the background papers were presented, followed by the working group sessions. The summary of the main points discussed during the working group sessions is presented below:

Potential and constraints for aquaculture development in Africa

Potential. Through aquaculture, opportunities exist both in terms of providing a source of income and employment and in improving the overall livelihood of farmers in Africa. However, compared to other continents, the aquaculture production of Africa remains insignificant. Africa's contribution to global aquaculture production in 2000 was only 1.1 per cent. Despite this, aquaculture development in the region shows considerable promise due to available resources (about 37 per cent and 43 per cent of surface areas are appropriate for artisanal and commercial fish production, respectively), suitability of farming in many different aquaculture systems (traditional, low-input, and commercial), and increasing demand for aquaculture products in local and world markets.

The acreage, productivity, and aquaculture operations that are contributing to rural development and national economies were used as criteria for discussions on the potential for aquaculture development in Africa. The participants concluded that the potential for aquaculture development in the region is high, but there are variations in terms of the relative potential of various production systems on national and sub-regional levels. There is a need for reliable aquaculture production data from these levels for better understanding of the status and trends of African aquaculture. It was pointed out that aquaculture production statistics from the national level are not very accurate, often due to weak and inconsistent data collection techniques and poor facilities for data analysis.

Constraints. While there is potential for aquaculture development, a number of constraints (i.e., biophysical aspects, marketing, inputs, policies, institutional and human resources) need to be addressed before the potential for aquaculture development in Africa could be achieved. These include: lack of knowledge of indigenous species for culture; cash-strapped local markets with limited purchasing power; consumer preference for larger fish in some countries (for example Egypt, Nigeria, and Uganda); competition from capture fisheries; non-availability of low-cost feeds; poor quality of fish seed and its insufficient quantity; lack of conduciveness of existing policies (for example land ownership and investment); lack of credit facilities (for both low-input and commercial culture systems); poor infrastructure for aquaculture (such as hatcheries in the public and private sectors); inadequate knowledge of farmers; and insufficient number of skilled extension personnel and their lack of skills.

Recommendations. Low management capacity has been identified as the main constraint to the development of small-scale aquaculture systems in Africa. To overcome this, adequate training for aquaculture research and extension personnel and the development of an information system for farmers' access to aquaculture technology should be provided.

There is, at present, high demand for quality fish seed in commercial aquaculture systems. However, this demand could not be met in view of the present constraints and limitations faced by the governments. Government hatcheries in many countries are either defunct or not able to provide quality seed in the required quantities. Few hatcheries started functioning in the private sector and most fish seed in culture operations, which are often of low quality, come from other farmers' ponds. New developments suggest that private sector hatcheries will play an increasingly important role in fingerling supply; hence there is a need to redefine the role of public and private sector hatcheries.

Overall, there has to be a strong commitment of government policy-makers and formulation of appropriate policies that will allow for the development of aquaculture in the region.

Status and potential for genetic improvement

Status. Genetic improvement of aquaculture species offers substantial opportunities to improve production, product quality and profitability of aquaculture. It was pointed out that in Africa, genetically improved fish breeds are both needed in commercial and small-scale aquaculture operations.

The development of Genetically Improved Farmed Tilapia (GIFT) technology that is based on traditional selective breeding and is meant to improve commercially important traits of farmed fish is one of the major advancements made in tropical aquaculture. This technology is now being applied for the genetic improvement of the growth rate, and extension of environmental tolerance of native tilapias in Africa. The work is being undertaken in government aquaculture stations of Cote d'Ivoire, Egypt, Ghana, and Malawi and in collaboration with the WorldFish Center. In South Africa, *O. mossambicus* populations from several water bodies have been recruited for initiating the selective breeding at the University of Stellenbosch.

The participants recognized that while the application of selective breeding to native tilapia stocks may be the suitable strategy for Africa, the main limitation is that improvement of fish through this technique takes a long time and is costly. In view of this, there is likelihood that instead of improving the native tilapia stocks, some commercial farmers may resort to importing improved tilapia strains developed elsewhere or introducing alien species (for example, introduction of *O. niloticus* to Zambia and Zimbabwe as this species grows faster than indigenous species).

Constraints for undertaking responsible genetic enhancement. Poor institutional structure and capacity were identified as the major constraints for genetic enhancement programs. Fish are not regarded as a priority in national food production and, therefore, resources allocated to genetic enhancement programs are either inadequate or lacking.

The existing infrastructure owned by governments or built through public funding can be used for producing improved breeds, but these are generally inappropriate for genetic studies since they are either poorly maintained or non-functional due to the lack of funds. It was also acknowledged that if these facilities were made operational, multiple functions and use of the same facilities for research and production may result in conflicts, but possible synergies might also exist to benefit genetic enhancement initiatives.

Capacity of staff at all levels for genetic enhancement studies is limited. In many countries, there are few geneticists and the small critical mass makes it difficult for them to influence decisions on genetic enhancement issues. This was also exacerbated by weak institutions and low capacity to train staff in this discipline. The lack of opportunity has resulted in poorly motivated staff.

Recommendations. There is an urgent need to address the ongoing genetic degradation of aquaculture species due to improper management. Genetic management of stocks is essential and must be the priority from the onset of domestication to prevent the degradation of stocks.

Strengthening the capacity (human and infrastructure) of national institutions in Africa on aquaculture genetics should be given priority. In view of the increasing interest of the private sector and farmers in improved tilapia strains and their important role in aquaculture development of the region, these stakeholders should also be involved in decision-making processes concerning genetic improvement programs and must be provided with training on the genetic management of stocks.

Genetically improved tilapia breeds are now available in the international market and there is likelihood that these improved strains will be introduced into Africa. In view of this, there is an urgent need for guidelines and policies for the genetic management of improved tilapias.

Risks of introducing improved strains and alien species

The introduction of improved fish breeds and/or alien species is likely to provide benefits. However, these may also present potential risks, especially in the countries of Africa where there is rich diversity of indigenous aquatic species that includes tilapias. When an introduced species escapes into waters where it is not native, it could become invasive and might pose a threat to native diversity and damage the aquatic ecosystem.

Apart from possible contamination of native diversity due to escapes of domesticated and introduced tilapia strains, the poor breeding facilities, lack of genetic enhancement capacity and limited number of individuals used as founder stock could aggravate the many risks involved in introducing improved tilapia strains.

Risk assessment and risk management need to pay attention to several dimensions that include: intervention techniques, species, habitat and ecosystem, level of intensification and traits for selection. For each of these dimensions, it should be possible to develop parameters for assessing the risks and (subsequently) monitoring the impacts.

It was felt that human health risk (however uncertain) should also be addressed pro-actively. It appears that the genetic interventions commonly applied in aquaculture would pose no risk of developing new proteins, a risk associated with some other genetically modified organisms and considered harmful to human health. Aquaculture stakeholders need to be aware that the subjective perception of health risks can in itself pose a considerable economic risk.

The level of risk to natural fish production will also differ according to countries. For example, risks are higher in Uganda because of its rich freshwater capture fisheries than in countries without significant water bodies. Decision-makers need to consider these differences when making decisions about introductions.

Risk assessment includes identifying hazards, events that could pose harmful consequences and quantifying risks – the probability of hazards occurring. Risk assessment must take a multi-sectoral and multidisciplinary approach, drawing on the expertise from different biological and social sciences. The time frame is an important dimension of risk assessment and is a crucial factor in the development of whatever consequences an introduction may entail.

The participants emphasized that risk management requires continuous monitoring, rather than individual assessments.

Recommendations. Introductions may be necessary for the development of aquaculture. However, any movement of fish between watersheds will need to be controlled and monitored. Mechanisms for the wider application of fish movement protocols and greater awareness in terms of their existence need to be considered. States in the region are responsible for the development and implementation of such protocols and regulations.

Decisions about the introductions need to balance the ecological impact (neutral or negative) and socio-economic impact (negative, neutral or positive). Guidelines based on available evidence must be developed for decision-makers (investors and consumers). Assessments as to whether impacts are "negative" or "positive" are to some extent subjective judgments. Different stakeholders may hold different opinions on the same evidence. This is true for ecological as well as socio-economic impacts.

There is a need to differentiate between the introduction of "new" and modified strains and the introduction of existing and wild strains into new water bodies (translocation).

Indiscriminate introductions and translocations by individuals and institutions are prevalent. These need to be addressed separately as they are likely to pose different types of risks and will require other kinds of mitigation measures. Experience seems to indicate that translocation may in some cases pose a greater risk than the introduction of modified strains, since existing strains appear more robust and more likely to become invasive.

Tools and protocols for the introduction and movement of improved fish breeds and alien species

Tools and protocols. A number of international codes of practices and protocols have been developed to deal with introductions, but there is a lack of clarity on the status of their implementation in the region. Protocols are useful in view of the following: (i) the already existing framework for regulating and monitoring the movement of plants and animals can be adjusted to include and handle the transfer of aquatic germplasm; (ii) the voluntary nature and user friendliness of most protocols allow for those committed to regulate and monitor movement of aquatic germplasm and to follow the protocols; and (iii) the precautionary nature of measures in most protocols allows for restricting movement even without establishing the exact impact of the movement of aquatic germplasm.

Constraints to implementation. While tools and protocols exist, to a large extent, their implementation has not been effective. This is mainly due to the voluntary nature of the protocols, which makes them non-binding, and the poor functioning of regulatory institutions. The latter is largely attributed to: (i) the lack of financial resources; (ii) inadequate knowledge and training in regulation of the movement and transfer of germplasm; (iii) lack of accountability; and (iv) inadequate quarantine facilities and services for aquatic germplasm, a major requirement for most of the protocols.

Recommendations. To address the constraints, it is necessary to: (i) provide knowledge and training on movement of aquatic germplasm and the need for its regulation and monitoring; (ii) increase efforts to make the protocols available; (iii) set up quarantine facilities for aquatic germplasm; (iv) improve the coordination and strengthen the present infrastructure to empower and train staff in the management and regulation of the movement of aquatic germplasm; and (v) for international and specialized agencies to monitor the use of existing protocols and report to interested countries the status of implementing them.

The presently available guidelines on managing the movement of aquatic germplasm in the region could be expanded to include the assessment of possible risks in the movement of aquatic germplasm. Developing local capacity is essential to accomplish this. FAO could be useful in monitoring the compliance levels and reporting this information back to the member countries and the international community in general.

There is much information that could help in managing the movement of aquatic germplasm, most of which is freely available and easily accessible; hence countries and individuals in the region should be encouraged to access it. The protocols and tools need to be fine-tuned on a country basis and must take into account the varied socio-economic and geographical systems to make them more useful and appropriate to the varied situations in the region.

The tools and protocols should be adapted as soon as possible, within current resource availability. It is also essential that these be improved at the national and regional levels through participatory and consultative processes.

As for non-binding international protocols, (for example the FAO Code of Conduct for Responsible Fisheries), it was thought that this could be made more binding and obligatory in all countries in the region with the enhancement and dissemination of knowledge and awareness at the national level.

In summary, five major conclusions were agreed on, based on the five key tools required in managing the movement of aquatic alien species and genotypes in the African region:

(i) Extensive databases on genetic diversity, environmental integrity and current practices are needed for background and baseline situation analysis. These data should be made available regionally as well as in each country for use in developing guidelines, protocols, management and impact assessment. Some of this information exists in partial form that may be further developed. However, there is, in general, a lack of awareness, knowledge and means to access and use them. It is suggested to establish a regional mechanism that could compile and disseminate the needed information and data including existing databases and collecting new information to allow for the effective use of the existing protocols and tools.

(ii) Internationally accepted protocols for reducing the risk of trans-boundary movement of pathogens through transfers and introductions of aquatic species exist. At present, such protocols for the movement of alien and modified genomes do not exist. The applicability of existing protocols seems currently difficult in Africa due to inappropriate models on which the protocols are based, lack of awareness, knowledge and absence of quarantine services required for the effective use of most of the existing protocols. It is suggested to examine the existing protocols and evaluate their applicability to African conditions. If found adequate, these should be applied immediately, and progressively ved through a feedback process. If not adequate, a new set of regionally applicable guidelines needs to be developed and for this technical and financial assistance may be necessary.

(iii) Risk assessment is an essential tool for making a priori decisions concerning the movement of aquatic organisms. It is a theoretical framework that incorporates knowledge of the species attributes such as trophic level, life history strategy, and taxonomic relatedness. The existing protocols for risk assessment were developed for non-African ecosystems and may not be directly applicable to the African situation in which case they may need adapting to specific situations. At present, there is a lack of complete data on the biological attributes of some species. It is suggested that the data collected be incorporated into simple versions of existing models, and begin to apply them in the region. This will permit immediate application of principles that can then be refined through a dynamic feedback system, eventually leading to well adapted systems.

(iv) Monitoring the environmental, social and economic impacts of alien species introductions should be an integral component of the process. Information and data collection processes do not appear to be widely in use in the region at the present time. However, based on existing databases and the state of knowledge on the African ecosystems, target reference points can be set for the achievements and limits for impacts of aquatic species movement. There is a lack of awareness, knowledge, and appropriate measures, and failure of information to be passed on among countries. It is suggested to establish and implement systems of monitoring that include data and information on basic species attributes.

(v) Awareness building is essential to support the management of the transfer of alien aquatic species and genomes, and to facilitate enforcement. Awareness in the region is not currently adequate within enforcement agencies and the general public. The protocols for moving aquatic germplasm are too recent, and financing and institutional structures for environmental awareness are inadequate. It is suggested that an awareness and communication strategy for the general public and enforcement agencies should be developed on the costs and benefits of moving alien genotypes. Governments should designate contact persons or institutions as information sources and put in place mechanisms for intra and international consultations and conflict avoidance.

Policies. Governments in Africa and regional and international bodies have formulated policies, laws, and legal instruments and protocols to regulate and control species introductions and protect the region's remaining biological resources. Examples are the National Environmental Policy; Policy on Wetlands; Plant Protection Act; Animal Breeding Bill and Fish Act of Uganda; National Environment Policy of Rwanda; Fish Act of Kenya; Coastal and Marine Act and Wildlife Act of Tanzania and Kenya; New Aquaculture Policy of Namibia that precludes the use of alien species in some areas; and Fisheries Protocol of the Southern Africa Development Community (SADC).

Most of the countries in the region are parties to relevant international conventions and subscribe to relevant Codes of Conduct. Examples of these are the CBD guidelines, the Cartagena Protocol on Biosafety, and the FAO Code of Conduct for Responsible Fisheries (CCRF). While such international conventions and agreements exist in the region, these have not been translated and adapted into national and regional policies. Moreover, international laws do not oblige nations to comply; hence, in general, they have not been implemented.

In addition, there are a number of regional agreements that regulate the translocation of germplasm within Africa. For example, in Eastern Africa, there is an agreement not to introduce Common carp (*Cyprinus carpio*) in the Lake Victoria Basin of Kenya, Uganda and Tanzania. Twelve SADC countries have signed the fisheries protocol and this includes some provisions on the control of introducing alien species. Apart from these, regional and sub-regional bodies (for example the Economic Community of West African States), although formed for economic and political issues, can be used as instrument for harmonization of policies. One of the weaknesses, however, is that in some regions (such as Eastern Africa), these agreements are only on paper and are not implemented in practice.

Several countries in the region have existing national policies or have produced policy drafts pertaining to the translocation and introduction of alien species. In Eastern Africa, some countries have fisheries laws (Fisheries Acts), which mention issues about translocations and introductions of alien fish species. In Southern Africa, some national policies are in place and institutional structures and regulating bodies exist to implement these.

However, while the above policies exist at the national level, they are either in draft form or outdated and have not taken into account new pressing and emerging issues (for example, the introduction of genetically modified and alien species). Moreover, most of these national policies are not specific to the conservation of aquatic biodiversity and have been focused largely on the protection of plants (mainly agricultural crops), and animal diversity.

The policies also lack strategies for development and implementation. The process of developing and implementing policies is not consultative or participatory and the interval between reviews of policies is too long. The development of policy is usually not based on scientific data and the responsibilities are often split among government ministries and agencies that act independently. Most often, these ministries lack a comprehensive understanding of fisheries and aquaculture. In some countries of West Central Africa (such as Ghana), there is absence of an appropriate ministry for fisheries, although an attempt is being made to create this. It was also felt that cross-cutting activities and multi-use of natural resources have resulted in overlapping and confusion of responsibilities.

Consequently, resultant policies may be incomplete and less than coherent. Often, policies are too complex; institutions lack enforceable regulations and communications between related institutions due to limited transparency and consultation processes and accountability may be low. In some instances, policies did not match legislation and available laws are not updated as institutions are becoming more multi-sectoral. The value of research in this field was also raised. It was felt that the value of the peer review process is not appreciated, and the results from some studies are questionable.

The participants have identified the following constraints for the implementation of existing policies:

- Lack of awareness and knowledge of legislation by the general public at all levels – resulting from a lack of participation by a wide range of stakeholders;

- Lack of coordination at the national, regional and international levels;

- Limited funding resulting in a lack of capacity (human and infrastructure) and strategies for implementation of the legislation;

- Outdated laws due to quickly changing socio-economic realities;
- Conflicts of interest (development versus conservation) and mandates of various authorities;
- Implementing authorities not being the right ones; and
- Lack of accountability, transparency and political will for implementation.

Recommendations. At present regional policies are formed by regional groups at the political and economic levels and ecological realities are not taken into account when establishing regional policies. Whereas national policies are paramount, these should be aware of sub-regional and watershed and basin-wide considerations. Efforts should be made to develop and implement effective policies and arrangements relating to the management of introductions into trans-boundary waters and watersheds.

Countries do occasionally examine the policies and legislation of their neighbors and sometimes adapt or adopt them. This occurs both within and across sub-regional groupings. In view of this, countries are encouraged to look beyond their borders for examples of workable policies and legislation, and adopt them in order to fill national policy gaps and harmonize them where necessary.

There is substantial variation in the development of aquaculture policy at the national level; however, there is a general absence of policies specific to the introductions, biosafety, and genetic enhancement. This reflects the recent history of genetic manipulations and improvements. In formulating policies, both conservation and development issues should be considered together to avoid conflicts of interests. Countries should develop, strengthen and implement policies on biosafety and genetic enhancement.

Countries are not sufficiently aware of the need for a biosafety policy and, therefore, this is not high on national agendas. Efforts should be made to improve awareness of policy-makers and resource managers and the general public (user groups) of the policies through campaigns, information exchange, and training. It is recognized that policy development is a long-term activity and in the short-term, awareness-raising may be more practical.

National adoption of international instruments and fulfillment of obligations are difficult because of the lack of resources (technical, human, infrastructure) and inappropriate assignment of responsibilities. The effectiveness of existing policies, laws and agencies also depends on the capacity of countries to engage in scientific analysis of the nature of living modified and improved species and related biotechnology processes. Countries should assign clear roles, responsibilities and budgets to agencies for the adoption and implementation of biosafety policies. The formulation and implementation of policies should be granted to the appropriate responsible authorities and should be guided by sound scientific data (for example an inventory of existing aquatic germplasm to provide baseline data for reference and identification of areas with undisturbed genetic materials for conservation). Countries without a ministry of fisheries and aquaculture should also consider establishing one.

There are strong provisions in the FAO CCRF dealing with alien species, genetically altered species, and conservation of aquatic organisms. Many countries in Africa are members of FAO and, therefore, have committed to implement these provisions. However, this will also require external assistance. National governments should link the implementation of the CCRF to their own policy-making and regulatory frameworks for aquaculture, fisheries, and nature conservation.

Policies are often formulated with limited consultation and participation; hence they are often unknown to users or viewed by users as restrictive. Policy and legislation formulation and implementation should be transparent, consultative, and participatory. They should consider the interests of all affected parties. They should involve all stakeholders and users. Incentives should be included for user compliance with the policy.

There is a need for impartial advice on the use of alien species and genetically improved species. Independent and scientifically competent expert bodies should be constituted at the sub-regional level, preferably as part of existing organizations, for example East Africa – BIO-EARN, West Africa - ECOWAS, and Southern Africa – SADC. These organizations should seek technical support and linkages with relevant national institutions and international bodies such as the FAO and the WorldFish Center.

There are a number of gaps in policies dealing with alien species and genetically improved species that should be corrected. For example, there is a clear lack of quarantine facilities and capacity in the region. Policies should be formulated that promote the establishment of quarantine facilities and fish health procedures, risk analysis and risk management procedures, and provisions for liability and rehabilitation.

Main Conclusions and Recommendations

Following four days of discussions, the participants endorsed the *Nairobi Declaration on the Conservation of Aquatic Biodiversity and Use of Genetically Improved and Alien Species for Aquaculture in Africa* (see following pages). The document, which outlines the main conclusions and recommendations of the workshop and has also been published under separate cover, serves as a guideline that will help foster the development of aquaculture in the region while maintaining biodiversity.

Nairobi Declaration

CONSERVATION OF AQUATIC BIODIVERSITY AND USE OF GENETICALLY IMPROVED AND ALIEN SPECIES FOR AQUACULTURE IN AFRICA

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

If this gap is to be bridged, capture fisheries need to be sustained and the potential of aquaculture realized. In doing so, attention needs to be given to protecting the rich aquatic biodiversity of Africa, especially the rich diversity of freshwater fish and its role in sustaining capture fisheries and providing species for aquaculture.

At present, fish production from aquaculture in Africa is low. However, as the population increases, together with the demand for fish, the aquaculture sector is projected to grow. For this to happen a wide range of constraints needs to be addressed and a greater range of management practices considered. Pond and broodstock management will need to be improved, a wider range of feeds developed, and market access improved.

In addition, there is considerable potential for improving performance of the fish species and strains used. At present, many of the fish used in aquaculture in Africa are derived from undomesticated stocks. This contrasts with crops, livestock and poultry where large increases in production have been achieved through the application of breeding programs and other genetic improvement procedures. However, while improved strains and introduced species have a potential to increase production, there is a clear risk of escape into the wild, and possible negative impacts on biodiversity. If the full potential for sustainable aquaculture in Africa is to be realized, these concerns must be addressed.

Recommendations

1. Quality seed

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

2. Genetics in broodstock management

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

3. Responsible introductions

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

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

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

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

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

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

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

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

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