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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

THE USE AND EXCHANGE OF AQUATIC GENETIC RESOURCES FOR FOOD AND AGRICULTURE

by

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ABOUT THIS PUBLICATION

The Commission on Genetic Resources for Food and Agriculture (the Commission), at its Tenth Regular Session, recommended that the Food and Agriculture Organization of the United Nations (FAO) and the Commission contribute to further work on access and benefit-sharing, in order to ensure that it moves in a direction supportive of the special needs of the agricultural sector, in regard to all components of biological diversity of interest to food and agriculture.

At its Eleventh Regular Session, the Commission agreed on the importance of considering access and benefit-sharing in relation to all components of biodiversity for food and agriculture, and decided that work in this field should be an early task within its Multi-Year Programme of Work (MYPOW). Accordingly, the Commission decided to consider arrangements and policies for access and benefit-sharing for genetic resources for food and agriculture at its Twelfth Regular Session (19-23 October 2009). To facilitate discussions and debate on access and benefit-sharing for genetic resources for food and agriculture at the Twelfth Regular Session, the Secretariat of the Commission has commissioned several background study papers on use and exchange patterns of genetic resources in the different sectors of food and agriculture. The studies provide an overview of past, current and possible future use and exchange patterns, as well as a description of terms and modalities for use and exchange of animal, aquatic, forest, micro-organism genetic resources; and of biological control agents. The current Background Study Paper deals with aquatic genetic resources for food and agriculture. Cross-sectoral studies have been commissioned to analyse use and exchange patterns in light of climate change and to review the extent to which policies and arrangements for access and benefit-sharing take into consideration the use and exchange of genetic resources for food and agriculture in particular.

The broad ranges of studies are intended to provide insight, necessary to maintain, establish and advance policies and arrangements for access and benefit-sharing for biodiversity for food and agriculture. The studies may also contribute to the negotiations of an International Regime on Access and Benefit-sharing in the Ad Hoc Open-ended Working Group on Access and Benefit-sharing under the Convention on Biological Diversity.

EXECUTIVE SUMMARY

Aquaculture has become the fastest-growing food production sector in the world with an average annual growth rate of 8.7 per cent since 1970; almost one-half of the food fish consumed by humans now originates on farms. Global aquaculture production of aquatic animals in 2006 was 51.7 million tonnes, valued at US $78.8 billion, with developing countries accounting for over 80% of this production. More taxa of aquatic animals are being farmed, in more places, than ever before. In 2006, aquaculturists farmed over 300 species of fish and invertebrates.

In order to inform future discussions on access to aquatic genetic resources (AqGR) and on sharing the benefits derived from their use, seven indicative groups of farmed aquatic animals were reviewed:

- Common carp *Cyprinus carpio*;
- Pacific salmon *Oncorhynchus spp,* and Atlantic salmon *Salmo salar*;
- Nile tilapia *Oreochromis niloticus;*
- Tropical catfish *Clarias spp* and striped catfish, *Pangasianodon hypophthalmus;*
- Marine shrimp;
- Selected molluscs*;* and
- Emerging aquaculture species as important food fish, ornamental fish and for recreational use.

Aquatic genetic resources provide the raw materials that enable breeders to improve aquatic animals through selective breeding, hybridization, chromosome-set manipulation, sex-reversal, production of mono-sex populations and gene transfer. Once captive breeding is possible, stocks with other value-added features can be more easily developed, such as specific pathogen free (SPF) stocks of marine shrimp.

The application of genetic technologies has added value and improved production in aquaculture species, although there is a wide-range of levels of domestication, genetic improvement and dependence on wild populations. Most production of farmed salmon, tilapia, tropical catfish, common carp and marine shrimp relies on domesticated stocks. In addition to domestication, selective breeding programmes have stimulated increased production of salmon, trout, tilapia and common carp. Hybridization has produced benefits for culture of tilapia and *Clarias* catfish but has not been important in production of marine shrimp, salmonids or bivalves. Chromosome-set manipulation has been used to increase growth rate in oysters and common carp, but has not been used in marine shrimp, catfish or tilapia production. No genetically modified aquatic species are commercially available at present.

While advances in molecular genetics and genomics have made it possible to understand the genetic basis for traits that are important in aquaculture, there has so far been little genetic characterization of the many breeds, stocks and strains of aquatic farmed species.

As farming of most aquatic species on the current scale is a relatively recent activity, many farmed populations are similar to wild relatives and may rely on periodic re-infusion of genes from wild populations. Breed improvement often involves collecting genetic resources from different geographic locations of both wild and farmed populations to create a diverse gene pool. Global dispersal of improved breeds, and continued local improvement, often follow; Atlantic salmon, marine shrimp, tilapia and common carp provide examples.

The aquaculture sector is composed of small- to large-scale farms that grow a wide variety of species in different geographic areas. There is some segregation into seed production and grow-out facilities. The sector is further partitioned into private and public sub-sectors. In China, for example, strains of common carp are produced and distributed by government-supported breeding centres; in Europe, many government carp breeding centres became privatized due to political re-organization, while production of salmon, marine shrimp and molluscs is now carried out mostly by private business.

While a few strains are being lost through lack of use (e.g. common carp), there does not seem to be a loss of genetically diverse strains of the cultured species examined in this paper. The genetic diversity within many cultured stocks has, however, generally been reduced compared to wild stocks. Reduced farmed diversity has often led to decreases in performance and the resulting need to infuse new genes from wild populations or from other farmed stocks. Wild relatives of farmed aquatic animals still exist in nature and their genetic resources continue to play a role in the production of several cultured aquatic commodities. However, many wild relatives have experienced declines in abundance and genetic diversity.

Brood fish taken from the wild are used in many culture based fishery stocking programmes, e.g. Pacific salmon. Wild AqGR are also critical in developing new species for aquaculture. Reliance on wild stocks for the starting material for aquaculture commodities provides an incentive to conserve those resources and to provide reservoirs of genetic diversity for future use. Aquaculture can also provide an alternative to harvesting wild resources.

The exchange and wide use of aquatic genetic resources have been important contributors to the recent growth of aquaculture. Aquaculture is the main reason for the deliberate movement of aquatic species to areas outside of their native range. Most genetic resources considered in this report are farmed in areas beyond their natural distribution. Patterns of exchange of AqGR of the farmed species examined here indicate very little flow of material from developing countries to more developed countries. Movement of AqGR and especially domesticated strains has often reflected the fact that technology and funding are necessary to produce improved strains, and that there has been relatively little domestication of aquatic species until recently.

The main sources of AqGR for commercial purposes are large commercial farms or breeding centres. There is a current trend in some species to reduce exchange and to develop local strains of farmed animals in response to concerns about the spread of disease. Such a shift may indeed limit the exchange of biological material, but it will increase the need to exchange technology and information.

Traditional knowledge about AqGR generally concerns natural history and ecosystem information. While this knowledge is valuable from an ecological or fishery perspective, it is not the type of information that is useful to those who want to develop improved aquaculture stocks. Because commercial-scale breeding of most aquatic species has only been possible within the last several decades, there is neither the depth nor range of breeds and associated traditional knowledge that exists for crop varieties and livestock breeds.

Policies on the use and exchange of AqGR are generally lacking. The exchange of AqGR is mostly regulated through private law, business contracts and national policies on environmental protection and disease prevention; material transfer agreements are also used. However, most policies and national legislation do not include ABS issues, although some examples do exist. The international ABS regimes that have been established have not been implemented at national or regional levels and there is little awareness among AqGR stakeholders of ABS issues.

A variety of views exist on the utility of ABS regimes. For the genetic resources considered here the general conclusion was that stakeholders do not place high priority on ABS issues. Lack of ABS implementation has not prevented the development of the sector nor denied providers of AqGR benefits. However, indigenous communities and commercial aquaculturists may have different value systems. Therefore negotiating access to and benefits from AqGR must take into account these different perspectives.

Other international, regional and national instruments regulate the exchange and use of AqGR, however ABS issues are generally not included. International and national legislation or business policies do not appear to have hindered the development of aquaculture. International mechanisms such as the Convention on Biological Diversity, the FAO Code of Conduct for Responsible Fisheries and the ICES Code of Practice on the Introduction and Transfer of Marine Organisms promote both use and conservation of AqGR. National policies have often been less restrictive than international ones, for reasons that include a low concern for introduced diseases, lack of awareness of ecological issues, difficulties in enforcement and a desire to stimulate trade. However, some countries have very restrictive regulations on exchange of AqGR. In some instances, local governments have labelled some aquaculture species as “invasive”, and have prohibited importation.

The use and exchange of AqGR have contributed significantly to the global success of aquaculture. Aquatic species have value as commodities, e.g. food, and as genetic resources for breeding. However, the value of the exchange of living AqGR for aquaculture is difficult to determine because data on traded commodities and fish products do not usually differentiate between products from cultured and wild fisheries. Nor do statistics differentiate between material moved for breeding or for grow-out. Because of their adaptability, the different aquatic species and breeds have allowed the industry to expand, respond to consumer preferences, and maintain production in areas where original species became devastated, for example by disease. Aquaculture is thus an adaptive and resilient farming practice that provides both direct and indirect food security and poverty alleviation. Common carp and tilapia, for example, provide local food security to small and rural communities as well as provide export opportunities for larger-scale commercial farms. In many cases, poverty is reduced and food security increased through the economic activity that aquaculture brings to communities.

Future Access and Benefit Sharing (ABS) regimes should recognize that for the industry to continue to grow, it will be necessary to bring new species into culture in a responsible manner, and exchange existing alien or native farmed species that are domesticated and genetically improved. At present, there are few policy initiatives directly relating to ABS for farmed aquatic species. Most regulations on use and exchange of AqGR have been designed to protect receiving countries from disease and environmental harm, whereas ABS measures tend to focus on the provider or source countries. Some ABS issues are beginning to be raised, for example, compensation for Norway’s provision of domesticated Atlantic salmon to other countries; a move to allow Africa to access tilapia that were genetically improved in Asia; and addressing indigenous peoples concerns about access to natural resources and development in traditional fishing areas. The regulators and stakeholders of AqGR in aquaculture need to become engaged in the process of ABS development.

BACKGROUND AND PREPARATION OF THIS DOCUMENT

To facilitate the Commission's consideration of access and benefit sharing of genetic resources for food and agriculture, the Commission, through the Aquaculture Management and Conservation Service (FIMA) of FAO, contracted the Network of Aquaculture Centres in Asia and the Pacific (NACA), an inter-governmental agency, mandated to facilitate regional R & D pertaining to aquaculture development, to commission reviews on specific aquatic genetic resources important in aquaculture. These reviews were presented and discussed at an expert meeting[2] on the use and exchange of aquatic genetic resources in aquaculture. This report is a synthesis of the information presented in the reviews and discussed at the expert meeting; supplemental material was incorporated into the document during finalization of the document. The reviews referred to above will be published in a special issue of the journal *Reviews in Aquaculture.*

[2] FAO/NACA Expert Meeting on the Use and Exchange of Aquatic Genetic Resources Relevant for Food and Agriculture, 31 March – 02 April, 2009, Chonburi, Thailand. http://www.enaca.org/modules/genetics/index.php

INTRODUCTION

More than half of all vertebrates are fishes, and the actual diversity of the major groups of organisms is greater in aquatic environments. With the number of known marine and freshwater fish species currently around 25,000 and climbing, there is clearly very high biological diversity at both the species and ecosystem levels. At the genetic level, unique populations of the same species are more common in fresh waters than in marine ecosystems.

Marine and freshwater biodiversity are quite dissimilar. Ninety-seven and half percent of global waters are marine, and oceans cover 71% of the world's surface. Marine biodiversity includes not only fishes but also a huge variety of invertebrates (many of which are heavily fished), as well as plants and microscopic life. Most marine biodiversity is harvested along coastal zones and the continental shelf, but many of the more inaccessible marine areas are little explored (Greer and Harvey 2004).

In contrast, fresh water makes up less than 0.5% of water on the planet, and only a tiny fraction of the world's fresh waters is actually available to support life. Nevertheless, inland waters contain an astonishing 40% of all aquatic species. Genetic erosion is a greater concern for freshwater species; it is more difficult to extirpate a marine fish species than an inland one. There are many examples of drastic reductions of freshwater biodiversity, through extirpation of species (such as the disappearance of many cichlid species from Lake Victoria) or removal of genetically distinct populations (such as the disappearance of wild Atlantic salmon from river systems in North America and Europe) (Greer and Harvey 2004).

Aquatic biological diversity primarily provides food (through capture and culture fisheries), but it also supplies the ornamental fish trade, as well as plants and animals for medicinal use. In terms of goods and services, inland waters contribute more to global economies than all terrestrial ecosystems combined, including forests, grasslands and rangelands. Global fisheries concentrate on only a tiny fraction of the known fish species. Nevertheless, all the rest have enormous importance because they generate ecosystem services by regulating food web dynamics, sediment processes and carbon supply, and by acting as links among ecosystems.

Genetic variability provides a range of options that helps species survive. For aquatic species, these genetic options are also of inestimable value in aquaculture (Bartley and Pullin 1998), which is the focus of this report. Aquaculture products contribute significantly to food security, are vital components of international trade and are an important source of foreign exchange for many developing countries.

Aquaculture has become the fastest-growing food production sector in the world with an average annual growth rate of 8.7 per cent since 1970. Global aquaculture production of aquatic animals in 2006 was 51.7 million tonnes, with a value of US $78.8 billion. Per capita, food supply from aquaculture has increased from 0.7 kg in 1970 to 7.8 kg in 2006. Developing countries provide ~80% of this production. Today, almost one-half (47%) of the food fish consumed by humans originates on farms, and this percentage is expected to increase over the coming decades (FAO 2009).

Commercial finfish aquaculture has so far emphasized freshwater species. Marine species may represent the next wave of cultured aquatic animals, and will likely target export markets. Two examples of emerging, high value cultured marine finfish are grouper and bluefin tuna. Recent advances in controlled reproduction of tuna underscore the rapidity with which well-funded research can proceed, and the genetic resources of cultured bluefin are not likely to be considered common property. On the invertebrate side, marine cultured species outnumber freshwater ones. Although not covered in this report, marine invertebrates are also well-documented sources of bioactive compounds, and technologies for culturing them can be expected to emerge (Greer and Harvey 2004). Again, heavy investment in this process will result in genetic resources that are unlikely to be freely exchanged.

In 2006, aquaculturists farmed over 300 species of fish and invertebrates (Figure 1). Many of these species are produced in areas outside their native range. Ancestral stocks of some of these species were often bred locally and then transferred to other areas for genetic improvement. Thus, exchange of genetic resources at the species level has been a significant component in the growth of aquaculture.

While domestication of aquatic species is taking place and is expected to increase, most aquatic species farmed today are still genetically very similar to their wild relatives. Although formal genetic improvement programmes have yet to become the norm in aquaculture, advances in breeding, molecular biology and animal husbandry are beginning to find application.

This document reviews the use and exchange of several indicative groups of farmed aquatic animals in order to inform future discussions on access to the aquatic genetic resources they represent, and on sharing the benefits derived from their use.

CHAPTER I: Scope of the study

1. Aquatic Genetic Resources (AqGR) in Aquaculture

This document focuses on AqGR used and exchanged in aquaculture. The AqGR of farmed aquatic species represents a small fraction of the total AqGR in nature and its management and development in aquaculture do not yet reflect its potential to improve production, sustainability and food security (CGRFA 2007). The genetic resources considered in this synthesis include the DNA, genes, gametes, embryos, farmed and wild populations, species, and genetically altered forms of farmed aquatic animals. Genetically altered forms include, *inter alia,* selectively bred strains, hybrids, polyploids and transgenes. Seven species/species groups that are indicative of current aquaculture were selected for coverage[3]:

- Common carp *Cyprinus carpio* (Jeney and Zhu 2009);
- Pacific salmon *Oncorhynchus spp,* and Atlantic salmon *Salmo salar* (Solar 2009);
- Nile tilapia *Oreochromis niloticus* (Eknath and Hulata 2009)*;*
- Tropical catfish *Clarias spp* (Na-Nakorn and Brummett 2009) and striped catfish, *Pangasianodon hypophthalmus* (Nguyen 2009)*;*
- Marine shrimp (Benzie 2009);
- Selected molluscs, (Guo 2009); and
- Emerging aquaculture species with food, ornamental and ecotouristic value (Nguyen et al. 2009).

These animals represent important aquaculture species from three major taxonomic groups: finfish, bivalve shellfish, and decapod crustaceans. They were selected for this study because they are well-established as farmed species in both tropical and temperate areas in developed and developing countries; they have been domesticated and are continuing to be domesticated to varying degrees; they are widely exchanged either internationally or regionally; they are grown in a variety of production systems; they represent the range of small-to large-scale aquaculture; a range of genetic technologies has been used to increase their production; and they depend to differing degrees on wild genetic resources. Emerging species were also examined to see how present patterns of use and exchange might apply to future aquaculture development.

Because this synthesis examines patterns of use, it focuses on aquatic animals with a farming history rather than on species that might be farmed in the future. However, the analysis of these established patterns provides lessons that will be applicable to access and benefit sharing of the genetic resources of newly farmed aquatic species as well.

2. Users and Uses

Aquaculture is a diverse agricultural activity that uses a wide-range of farmed species in a variety of production systems. The users include not only farmers but also an extended supply chain ending at the consumer. For this study, the focus was on producers and those that exchange AqGR for breeding and grow-out for the production of food, some ornamental fish and bait fish, as well as for release into natural or modified water bodies for purposes of stock enhancement. It is difficult to distinguish between the exchange of AqGR in aquaculture for breeding and for grow-out, because many genetic technologies allow for further breeding after grow-out, and records do not usually distinguish between those uses. Production of bioactive compounds and pharmaceuticals are not addressed because these are not thought to be important in aquaculture at present, even though some animals used in traditional

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[3] The references here represent the review papers commissioned for this study on which this synthesis was based. They will be published in late 2009 in a special volume of the journal *Reviews in Aquaculture* by Willey-Blackwells.

medicine, such as sea horses, are now cultured. Farming of ornamental species for the aquarium and home garden market is an emerging topic. Genetic resources of aquatic plants and aquatic microbial organisms are not included in the study.

Aquaculture facilities include small-to large-scale farms (based on the amount of land utilized and product produced); extensive-to highly intensive farms (based on the level of inputs); and subsistence-to commercial facilities (based on whether the product is meant for home consumption or for sale). Farms can be located in highly developed areas such as urban or peri-urban areas, in agricultural zones, or in less developed areas such as coastal, mountain or riverine habitats (CGRFA 2007).

AqGR provide raw materials that have been used to produce a variety of fish food products and have allowed aquaculturists to raise over 300 species of aquatic animals belonging to many different taxa. Aquatic animals are amenable to improvement through the use of several genetic technologies (Table 1), and numerous varieties of genetically altered animals have been created. Because farming of most aquatic species is a relatively recent activity, much culture is reliant on wild stocks to maintain broodstock supply and to provide the base or supplemental broodstock for genetic improvement programmes. Thus, many farmed populations are similar to wild relatives. For example, the genetic improvement of Nile tilapia (Box 1) infused genes that were collected from wild populations as a common property resource in order to create a genetically diverse breeding population (Box 2).

Table 1. Genetic technologies used for the improvement of aquatic species

Short-term genetic improvement	**Description**	**Purpose**	**Example**
Hybridization	The breeding of genetically distinct groups, either within a species or between species.	To combine the advantageous qualities of two different groups of animals, e.g. fast growth and good meat quality. May also be used to reduce or eliminate reproduction.	*Clarias* catfish from Africa and Thailand have been hybridized to take advantage of the fast growth of the African species and the flesh quality of the Thai speciesn (Na-Nakorn and Brummett 2009).
Chromosome set manipulation	Addition of chromosome sets through chemical, pressure or temperature shocks to gametes or fertilized eggs.	To improve growth and meat quality in some species and to limit reproduction.	Pacific oysters with an extra chromosome set, i.e. triploids, are sterile and do not develop gonads which reduces flesh quality. Thus, flesh quality and marketability are maintained throughout the year (Guo 2009).
Sex reversal	Production of mono-sex groups through hormone treatment and breeding.	To eliminate reproduction in grow-out and take advantage of sexual dimorphism.	Groups of juvenile Nile tilapia can be made all male by the application of hormones; subsequent breeding of sex-reversed tilapia can be used to create additional all male groups without the use of hormones (Eknath and Hulata 2009).
Long-term genetic improvement			
Selective breeding	Traditional animal breeding where the "best" animals are bred generation after generation, while minimizing inbreeding.	To take advantage of additive genetic variance that continuously improves culture performance for such traits as growth rate, body shape, environmental tolerance, disease resistance, pollution resistance and time to maturity.	Growth rate of Nile tilapia increased by 12-17% per generation as a result of selective breeding for growth and survival (Eknath and Hulata 2009).
Gene transfer	The use of genetic engineering and recombinant DNA technology to insert genes into a species in which they would not naturally occur.	To create new forms of a species with improved characteristics (e.g. growth rate and environmental tolerance), the type or level of which is not possible through other strategies.	Chinook salmon growth hormone gene combined with an anti-freeze promoter gene from the ocean pout allows Atlantic salmon to continue to grow during cold season when growth would normally cease. Increased size of 200 – 600% observed after one year. (Shao Jun Du et al. 1992).

CHAPTER II: Use and Global Exchange of Aquatic Genetic Resources, and Sharing of Benefits Derived from Them

1. Use of genetic resources (past/ status/ trends)

a. Extent of use/ addition of value

i. Main uses of aquatic genetic resources

Four uses of AqGR are considered in this synthesis. The primary one is breeding of aquatic species for *food production* through aquaculture, defined as "the farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated" (FAO Aquaculture Glossary). Aquaculture facilities are also used to produce animals for release into natural or modified water bodies for *stock enhancement*, also known as *culture based fisheries* (FAO Aquaculture Glossary). Culture based fisheries exist for both commercial and recreational species. Aquaculture is also important in the provision of *bait fish* for commercial and recreational fisheries, primarily in inland waters; cultured bait fish production is gaining popularity because it reduces the spread of disease by wild-caught bait fish and may help to protect wild species of bait fish that are becoming endangered. For example, *Clarias* catfish are being farmed as bait for Nile perch in Lake Victoria in efforts to stop the harvest of wild and endangered native fishes (Na-Nakorn and Brummett 2009). Finally, the farming of *ornamental fish,* in particular freshwater fish, is increasing as more species are being bred in captivity. Because some wild populations of ornamental fishes are threatened, the culture of such species may also have a conservation value.

ii. Extent to which resources have been domesticated or genetically improved

It has been estimated that 5-10% of all aquaculture production is derived from systematic breeding programmes (Gjedrem 2005). If, however, one considers production from those species that an aquaculturist can breed in captivity, rather than the more restricted "systematic genetic improvement", the contribution increases considerably. Of the genetic resources considered here, there is a wide-range of levels of domestication[4] and genetic improvement. In some cases, particularly mollusc culture and to a lesser extent in finfish, aquaculture still depends on collection of wild genetic resources (e.g. eel, tuna). Most production of farmed salmon, tilapia, catfish and common carp for direct consumption, and approximately 70% of marine shrimp production (e.g. *Penaeus. vannamei, P. stylirostris* and *P. chinensis),* relies on domesticated stocks (Benzie 2009; Eknath and Hulata 2009; Solar 2009; Jeney and Zhu 2009). This range of domestication, genetic improvement and reliance on natural genetic diversity is typical of the aquaculture sector.

The species covered in this paper are farmed and bred in numerous countries and by various user groups. The source of breeding material has been extremely variable even within a given species group. For example, marine shrimp breeding has involved use of wild caught adults, the use of shrimp taken from production ponds raised to maturity and bred in an *ad hoc* manner, and the development of long-term selective breeding programmes by commercial breeders in centralized breeding areas often outside the species' natural range (Benzie 2009).

Aquatic species are amenable to systematic genetic improvement and domestication as soon as the life-cycle has been closed in captivity (Table 1). Genetic improvement strategies can be characterized as short-term or long-term. Short-term strategies involve one or two generations or breeding cycles and the gains are usually limited to each breeding period; long-term strategies span several generations and the gains are usually cumulative. Both strategies rely on the ability to breed animals in captivity;

[4] Domestication is defined here to be the controlled breeding for at least three successive generations. See Bilio, M. Controlled reproduction and domestication in aquaculture. The current state of the art part II. Aquaculture Europe 32: 5-23.

long-term strategies rely more on systematic genetic improvement programmes to ensure maintenance of genetic diversity and avoidance of inbreeding.

The high fecundity of many aquatic species allows for intensive and rapid selection. Common carp is the aquatic species with by far the longest history of breeding and domestication, suggested to be at least 2,500 years (Balon 1974); more breeds and improved strains have been produced for common carp than for any other species. For all other species, controlled breeding has been a relatively recent activity. More species are being farmed now than ever before (see below section b. Trends in genetic diversity) and aquaculturists are faced with a decision on whether to domesticate new species or to genetically improve and differentiate existing species in order to satisfy consumer demand. In either case, the exchange of biological and breeding material will be essential for the sector to grow.

A. Short-term genetic improvement strategies

Hybridization between species is a rapid way to improve production without embarking on a long-term selective breeding program. Hybrids between the Thai catfish *Clarias macrocephalus* and the African species *C. gariepinus* constitute ~80% of Thai catfish production; hybrids between two African catfish species (*C. gariepinus* and *Heterobranchus longifilis*) are also used in Africa (Na-Nakorn and Brummett 2009). In Indonesia, hybrids of the introduced striped catfish *Pangasianodon hypophthalmus* and the local species *Pangasius jambal* are grown by both small- and commercial-scale farms (Nguyen 2009). Hybridization between tilapia species with different sex-determination mechanisms has been used to produce single-sex, mostly male, populations. In China and elsewhere, crosses between Nile tilapia and blue tilapia (*O. aureus)* yield all-male (or mostly male) offspring that have growth advantages over mixed-sex offspring (Eknath and Hulata 2009). Hybridization has generally not been used to improve culture performance of crustaceans, molluscs and salmonids.

Chromosome set manipulation or polyploidization through the addition of an extra set of chromosomes (for example, to produce triploids) was initially used as a way to restrict reproduction and thereby enhance growth (sterile triploid animals do not devote energy to reproduction). Xiangyun carp, a variety of triploid common carp in China, displays fast growth, good meat quality and strong disease resistance (Jeney and Zhu 2009). In other species, growth rate has generally not improved significantly, but sterile animals have become useful in oyster culture to maintain meat quality during the reproductive season, and to prevent animals from reproducing in the wild (Guo 2009). Although triploid salmonids are not common, they are farmed in some places where reproduction of escaped salmon would endanger native species by competing with them for food and spawning areas, or through hybridization and subsequent genetic dilution (Solar 2009). Polyploidization has not been used to improve marine shrimp (Benzie 2009).

Sexual dimorphism, where males and females have dissimilar growth and culture characteristics, exists in many species of fish. As a result, one sex is often preferred for production; for example, male tilapia usually grows faster than females. Groups of all-male tilapia produced through inter-species hybridization and sex-reversal have faster growth rates and less chance of uncontrolled reproduction than do mixed-sex groups. Genetically male tilapia (GMT) has been produced through hormonal feminization of male tilapia and subsequent breeding with untreated males. Through progeny testing, it is possible to identify YY super-males that will always produce male offspring when bred with normal females (Eknath and Hulata 2009).

Production of only one sex also has use to restrict unwanted reproduction. Uncontrolled reproduction in tilapia has led to overcrowding and reduced growth in production ponds. Tilapia are also quite likely to escape from certain kinds of enclosures and can rapidly establish in the wild. Single-sex populations have diminished reproductive capacity, which reduces their chance of breeding either in grow-out or after escape.

B. Long-term genetic improvement strategies

Gene transfer involves the insertion of functional genes (gene plus promoter complex) from one species into another; the animals resulting from this process are called genetically modified organisms (GMOs). Gene transfer is considered a long-term strategy because of the research involved in identifying useful genes and promoters, and the on-going analysis of how the new gene functions in farming systems. Although no aquatic GMOs are commercially available at present, and their use and exchange is not therefore possible to assess, several cultured species, including the widely farmed salmon and tilapia, have been genetically modified (FAO 2000). GMO versions of these species may be available to the aquaculture industry in the future.

Selective breeding strategies, including mass selection, family selection, or selection indices, are important in breed improvement, and are considered generally here as "selective breeding." Taken together, selective breeding programmes using traditional animal breeding principles have been extremely effective at improving production in farmed aquatic animals. Improvements are cumulative and accrue with each generation, leading to steady, long-term gains in production. Characters that have been improved through selective breeding in aquatic species include growth rate, body shape, environmental tolerance, disease resistance, pollution resistance and time to maturity. Well-designed selective breeding programmes have stimulated dramatically increased production of salmon and tilapia. Selective breeding of Atlantic salmon in Norway focussed initially on improving growth rate, then on age at maturity, disease resistance and carcass quality (Solar 2009). Improvement of Nile tilapia was aimed at improving growth and survival (Eknath and Hulata 2009).

The ability to control breeding and reproduction in farmed aquatic animals is a necessary step in domestication and an important factor for increasing production. A significant factor in the increased production in white-leg shrimp, *P. vannamei*, the species that accounts for most marine shrimp production, is that the species can be bred in captivity and production does not rely on wild stock. The black tiger shrimp, *P. monodon,* has recently been captive-bred on a commercial-scale and may be expected to experience increased production as a result (Benzie 2009).

C. Trends in genetic improvement

Strategies for breed improvement often involve collecting genetic resources from different geographic locations to create a genetically diverse pool. Breeding programmes for several species were started in this way, with animals transported to central breeding centres. The genetic diversity found in natural populations provided an essential raw ingredient to the breeding programmes.

Atlantic salmon were genetically improved through selective breeding programmes in Norway and transported to both developed and developing countries, where local breeding programmes continue. Chile is now the world's second-highest producer of farmed salmon based on AqGR from the northern hemisphere (Solar 2009). Marine shrimp were also genetically improved in areas outside their native range. Stocks of *P. vannamei*, *P. stylirostris,* and more recently *P. monodon* were developed in the United States of America for distribution to developing countries in Asia, the Pacific islands and the Americas (Benzie 2009). In the case of Nile tilapia, AqGR from several locations in Africa were transported to the Philippines for genetic improvement and subsequent dissemination to other developing countries (Box 1). We have already noted that common carp, because of its wide environmental tolerance and ease of breeding, has been locally improved through generations of informal breeding; more recently, regional and national formal breeding centres have produced stable lines of genetically improved carp.

Box 1: Genetically Improved Farmed Tilapia – The GIFT Program (from ADB 2005 and Greer and Harvey 2004)
In the mid 1980s the International Center for Living Aquatic Resources Management (ICLARM now the WorldFish Center), in collaboration with Norwegian and Philippine

institutions, recognized the potential to genetically improve Nile tilapia through traditional breeding methods for the benefit of urban and rural communities. Nile tilapia is native to Africa and was chosen because of its role in freshwater aquaculture, its value as both an export and local food commodity, and its short generation time (~6 months) that would allow for rapid progress in selection programmes.

The GIFT Program had five main objectives: to develop an improved strain of Nile tilapia, to build national capacity in aquaculture genetic research, to disseminate GIFT, to evaluate the impacts, and to facilitate development of national tilapia breeding programmes. The developers wanted to create a general purpose strain of Nile tilapia that would perform well in a variety of environments and farming systems. Thus, it was necessary to establish a base population with sufficient genetic variability to allow for genetic improvement through traditional selective breeding methods. In order to ensure such genetic diversity, ICLARM and partners in association with national research institutions in Africa, collected Nile tilapia from four natural populations in Egypt, Ghana, Kenya and Senegal, and from four strains currently farmed in the Philippines. These strains were evaluated for inclusion in a GIFT breeding programme and a synthetic base population was established from these eight strains.

The GIFT Program was a success. Evaluation of the GIFT Program demonstrated that genetic gains of 12-17% per generation were possible through selective breeding, and improved strains were being farmed in many collaborating Asian countries. Estimates made by the WorldFish Center on economic benefits from the use and dissemination of GIFT indicated that a 70% internal rate of return on investment could be achieved from 1988 to 2010.

However, the synthetic GIFT base population was composed of alien genotypes that could potentially disrupt pure African tilapia populations if they escaped and interbred with local tilapia. Therefore, in order to protect the natural genetic diversity that made establishment of the GIFT possible, the trustees of the programme established a policy that Africa should receive development and technical assistance, but that the GIFT fish should not be returned to Africa; African aquaculturists and developers were to use the technology and training to develop their own improved tilapia. Several governments established environmental policies and regulations prohibiting the introduction of GIFT.

Although the intentions were laudable, the process of decision-making did not include some important African stakeholders, e.g. aquaculturists and local development groups. With the dissemination of GIFT in Asia and the documentation of the significant improvements in production, it was only natural that African aquaculturists, many of whom wish to compete for international markets with other farmers who export Nile tilapia, would want to farm a readily available improved fish, and not go through the process and expense of developing their own strains.

The GIFT Program started when genetic resources were still viewed as common property (that is, before the Convention on Biological Diversity was drafted) and few laws governing access or benefits were in place or enforced. In recognition of the principles of the Convention on Biological Diversity regarding a country’s sovereignty over its biodiversity and the benefits to be derived from the use and exchange of the GIFT in Africa, the policy of the WorldFish Center and the GIFT Foundation International, who are responsible for carrying on the GIFT legacy, has now changed to allow the importation of GIFT back into Africa where consistent with national policies and legislation. Several African countries have changed or are in the process of making the necessary changes to allow the use of GIFT resources.

The developers of GIFT followed international guidelines, a precautionary approach to species introductions, and material transfer agreements were put in place when GIFT were disseminated; to date, no adverse impacts from GIFT have been reported. The responsible reintroduction of GIFT will allow African communities to benefit from an

African genetic resource that was improved in Asia, and demonstrates the interdependence of countries and the importance of the use and exchange of aquatic genetic resources.

Once captive breeding is possible, stocks with other value-added features can be more easily developed; an example is specific pathogen free (SPF) stocks of marine shrimp. Although SPF stocks are not the result of genetic manipulation, they depend on a bio-secure, i.e. a disease free source of larvae, and this is greatly facilitated by captive breeding in hatcheries. SPF stocks that are truly independent of wild stocks are more secure – however, SPF is a term that may also be applied to animals from the wild where no specific diseases have been detected. Specific Pathogen Resistant (SPR) stocks have been developed for marine shrimp through selective breeding of naturally resistant strains (Benzie 2009). Because SPR stocks would not be expected to show clinical signs of the pathogen they are resistant to, there is some concern that SPR stocks could be carriers of harmful pathogens.

Table 1 lists other genetic techniques that are useful in aquaculture. The trend appears to be for increased use of domesticated animals where possible

With advances in molecular genetics and genomics it is becoming possible to understand the genetic basis for traits that are important in aquaculture (Benzie 2009). This information may become extremely important for breed improvement and, in cases like disease resistance in marine shrimp, may yield better results than traditional genetic improvement. To date, however, there has been little genetic characterization of the many breeds, stocks and strains of aquatic farmed species; descriptions are still based on morphology and colour (as in the many varieties of common carp), special characters (e.g. SPF marine shrimp), geographic location or trademarks (e.g. GIFT or GMT tilapia).

Genetic maps useful in marker-assisted selection (MAS), have been developed for some commodities. These markers attempt to indicate characters that are useful for improved farming. However, MAS is not common on a commercial scale. In marine shrimp, only a few characters of economic importance have been identified (Benzie 2009).

iii. Typology of main users of AqGR

The aquaculture sector is composed of small- to large-scale commercial farms using a wide variety of species in different geographic areas (CGRFA 2007). The majority of aquaculture in Asia is on farms of less than 2 ha, similar to other Asian agriculture sectors. For example, average farm size in Thai freshwater fish culture is less than 0.3 ha with an average production of 2300 kg/ha (S.S. De Silva, personal communication). Over 90% of Indian shrimp farms are less than 2 ha in area, and only 3% are greater than 5 ha. Small size holds for most agricultural activities in Asia, including the Indian dairy industry (in aggregate the largest in the world) and striped catfish (*P. hypophthalmus)* farming in Vietnam (Nguyen 2009). Nevertheless, although Vietnamese catfish production is based on small pond size, production of 400,000 kg/ha/crop has been achieved (Phan et al. 2009).

An extreme example of small-scale aquaculture is provided by the backyard static water holes in Bangladesh that can produce significant amounts of *Clarias* catfish for home consumption and sale (Na-Nakorn and Brummet 2009). In contrast, shrimp farms in Latin America tend to be large. Farming of salmonids throughout the world is mainly by large companies, following consolidation of many smaller operations (Oleson et al. 2007).

Because of the special needs for breeding and larval rearing of many species, and the difficulty of maintaining breeding programmes that keep genetically improved lines performing well, the aquaculture sector in certain areas has segregated seed production and grow-out (Benzie 2009; Eknath and Hulata 2009). Thus, many farmers buy seed from a single central hatchery. Proper broodstock management and adherence to well-defined breeding programmes are necessary to prevent degradation (poor performance) of broodstock through inbreeding or loss of genetic diversity.

The aquaculture sector is further partitioned into private and public sub-sectors. Strains of common carp are produced and distributed by government-supported breeding centres in Hungary, China, the Czech Republic and India (although in some areas national breeding centres are becoming privatized in response to political re-organization) (Jeney and Zhu 2009). In contrast, the production of marine shrimp (Benzie 2009) and molluscs (Guo 2009) is now carried out by private business. The Norwegian salmon farming industry, now the largest in the world, started out with public financing as a joint activity between farmers and a non-profit research institute, AKVAFORSK, which has since developed into a privately owned selective breeding company which develops, produces and delivers genetic material to a global salmon and trout aquaculture industry.

For many stock enhancement programmes that release juvenile fish to the wild, especially salmonids, government hatcheries produce juveniles intended to support culture-based fisheries. Government-run hatcheries in Japan, Canada and the United States of America produce and release billions of Pacific salmon in efforts to mitigate loss of natural spawning habitat and to maintain fisheries (Solar 2009).

b. Trends in genetic diversity

i. Are aquatic genetic resources being lost or gained?

More taxa of aquatic animals are being farmed in more areas than ever before. The number of species farmed has increased substantially since the 1950s, reflecting the relatively recent emergence of the sector. In 1950, countries reported farming 72 species from 34 families; by 2004, production was reported for 336 species from 115 families (FAO 2006). While some strains are being lost through lack of use and financial support (for example breeds of common carp in state-supported breeding centres in central and eastern Europe during the political and economic changes of the 1980-90s (Jeney and Zhu 2009)), increasing use of technology in breeding programmes and animal husbandry has contributed to a general improvement in strains and breeds, resulting in a major increase in aquaculture production. The rapid rise of Atlantic salmon and white-leg shrimp is due largely to increased use of controlled breeding (Benzie 2009). Although there is some evidence that genetic diversity is declining in farmed *Clarias* catfish culture in Thailand (Na-Nakorn et al. 2004), there does not seem to be a loss of genetic diversity in farmed marine shrimp or salmonids. Wild resources of many species have, however, experienced documented declines in genetic diversity due to a variety of factors such as habitat degradation and loss, overfishing and introduction of invasive alien species. This should concern researchers and breeders looking to collect wild genetic resources for further improvement of cultured species (see section III).

With development of improved breeds, care must be taken not to displace the few traditional varieties of farmed fish that do exist. When Asian catfish farmers adopted the hybrid between Thai and African catfish, they stopped farming the local pure species. However, the local species was not much improved genetically over the wild type and therefore there was no significant loss of genetic resources (Na-Nakorn and Brummet 2009). In another example however, a traditional red strain of common carp in Vietnam has a trait that allows it to remain resident in the rice fields, rather than migrate to other waters, so it is easy to control and harvest. Because other genetically improved common carp tend to leave the rice fields, their use could reduce production and put the traditional strain at risk (Greer and Harvey 2004). With the exception of common carp, no major losses of farmed AqGR have been observed to date, but future losses are possible.

The genetic diversity within cultured stocks, when compared to wild stocks, has generally been reduced by a variety of mechanisms such as founder effect, inbreeding, and small effective population size. This is a common phenomenon in the genetic resources studied here and in animal breeding in general. Reduced diversity has often led to decreases in performance and the need to infuse new genes from wild populations or from other farmed stocks.

ii. To what extent are wild aquatic genetic resources used in the farming of this commodity?

Wild genetic resources continue to play a significant role in the production of several cultured aquatic commodities, and the argument for saving wild or land-race agricultural genetic resources applies just as well to aquatic genetic resources. The wild relatives of farmed aquatic animals still exist in nature, although some populations may be threatened or endangered (see section III.2.on some access restrictions for wild populations). Common carp breeding in some areas relies on regular infusion of genes from wild or feral populations. Even with the genetic improvement of tilapia well under way in Asia, it is expected that wild populations of Nile tilapia in Africa will need to be conserved as a source of genetic material. The culture of several species of marine shrimp has historically depended on wild post-larvae and broodstock; most of the culture of black tiger shrimp *P. monodon,* the second largest marine shrimp commodity, still does to a significant extent (Benzie 2009). Wild AqGR can also be important in developing new species for aquaculture. Emerging species such as groupers (Epinephelinae) and mahseer (*Tor spp.)* rely on wild genetic resources at a time when there is concern that wild populations are being adversely impacted by fisheries exploitation and habitat destruction through anthropogenic developments (Nguyen et al. 2009). Access to wild AqGR has not been an issue in many instances because the resources are often considered common property. The collection of wild Nile tilapia from Africa was based on agreements between national research institutions (Box 1) and an international agency. (For contrast, see the example of Arctic charr in sections III and IV.)

Farming of Atlantic and Pacific salmon has for the most part eliminated the use of wild germplasm in commercial production of food fish. However, broodfish from the wild continue to be used in many culture based fishery stocking programmes. For example, mature salmon returning to spawn are captured and bred in order to produce juveniles that are raised in hatcheries until ready for release back into the wild. These fish may be used to rebuild natural populations or for enhancement of existing fisheries; their actual degree of “wildness” of course depends on the number of generations that have passed through the hatchery system (Solar 2009).

For emerging aquaculture species, initial dependence on wild resources is reduced following development of captive breeding technology relatively early in the development and commercialization of the aquaculture practices. Striped catfish (*Pangasianodon hypophthalmus*) were initially wild-caught; with Cambodia providing genetic resources to Vietnam; while Thailand provided striped catfish to Indonesia, Myanmar and Bangladesh. However, wild seed collection was officially banned after captive breeding became possible in order to protect natural stocks and facilitate reproduction. In the case of striped catfish, once hatchery production and transport of fish becomes common, there is often little concern for identifying the origin of the AqGR (Nguyen 2009). Similar cases of extensive movement of genetic material have been seen in other species once hatchery production is possible—for example, several species of marine shrimp. For the long term, such an attitude is ill-advised; for example, cobia (*Rachycentron canadum)* is a newly farmed marine fish for which the majority of farmed stocks in Asia are thought to have come from a limited source in Taiwan Province of China (Nguyen et al. 2009). As in most kinds of farming, a narrow genetic base is seldom a good thing. Information on the origins and composition of farmed AqGR will help in managing wild resources to maintain adequate genetic diversity.

For some taxa it is becoming difficult to find wild fish populations with genetic resources that have not been influenced by genes from con-specific relatives transferred to areas beyond their natural distribution, or from related species that have either escaped from culture or have been transferred into the area for other reasons. In some parts of Norway, for example, escaped farmed Atlantic salmon are more prevalent than wild salmon, and many populations of Nile tilapia in Africa have been introgressed with genes from introduced stocks. The use of *Clarias* hybrids in Thailand has been implicated in the genetic degradation of wild *C. macrocephalus* populations. There has also been a reduction in the number of pure *Clarias* species in Thai markets, although this could also be due to inappropriate use of pesticides in rice fields where wild *Clarias* are traditionally captured (Na-Nakorn and Brummett 2009).

2. Global exchange of genetic resources (past/ today/ trends)

Aquaculture is the main reason for the deliberate movement of aquatic species to areas outside of their native range,[5] and farmed species have been moved extensively throughout the world. For example, although salmon do not naturally occur in the southern hemisphere, Chile is the world's second largest producer of farmed salmon, and Atlantic salmon is now grown in Tasmania, Australia as well. Asia is the number one producer of African tilapia, and more white-leg shrimp, which are native to the Americas, are farmed in Asia than are the local species. The rainbow trout (*Oncorhynchus mykiss*) and other trout species have been extensively introduced around the world for recreational purposes, fishery development and aquaculture; and the Pacific oyster from Japan is the basis for the oyster industry in North America and Europe (FAO 2006).

a. Type of genetic resources exchanged

Exchange of AqGR involves gametes and fertilized eggs (salmonids), larvae (oysters and other molluscs), post-larvae (marine shrimp, molluscs), and juveniles (tilapia, carp, catfish). The early life history stages of many aquatic species are easily transported over long distances and require very little shipping space; some gametes and embryos can now be cryopreserved and shipped at high concentrations in cryogenic containers originally developed for cattle and equine genetic material. There is substantial transfer of disease- free stocks of salmon, for example from Norway to Chile, and of SPF shrimp from the United States of America to Asia and Latin America. Although efforts are directed at movement of disease-free stocks, there is still a risk of introducing unknown pathogens, and therefore exchange is beginning to be reduced, especially in salmon and shrimp aquaculture (Benzie 2009; Solar 2009).

b. Main sources of AqGR

Apart from the reservoir of potential genetic diversity in wild populations, the main sources of AqGR for commercial purposes are large commercial farms or breeding centres, and to a lesser extent live gene banks for some commodities such as common carp. Although national governments were responsible for much of the initial exchange of AqGR, commercial farms or breeding centres now provide the majority of genetic material for exchanges for the resources discussed here.

Sources of AqGR vary among the genetic resource groups studied here and have changed as the aquaculture industry and breeding capacity have improved. For example, early shrimp farms accessed wild broodstock or collected wild larvae and exchanged these among countries within the species natural range. Concerns over disease transmission and improved culture qualities have led to the establishment of commercial breeding facilities that supply genetically improved and SPF shrimp to a global market (Benzie 2009). Similarly, oysters were originally collected from the wild, but as they were moved to different areas and disease problems arose, the use of disease free and disease resistant strains from commercial hatcheries became more common (Guo 2009). Salmonid breeding is exclusively based on genetically improved strains; the main source of domesticated Atlantic salmon being Norway (Solar 2009). Common carp breeding centres in Asia and Europe maintain a diverse array of genetically differentiated carp strains that are exchanged for commercial development and for food security (Jeney and Zhu 2009). Conditions for accessing breeding material from commercial farms are usually based on private contracts, but little attention regarding access is usually afforded collections from the wild except in developed countries where collection permits or fishing licenses may be required (see section III).

Commercial-scale breeding of most aquatic species has only been possible within the last several decades, with the ancient breeding of common carp the notable exception. As a result, there is neither the depth nor range of breeds and associated traditional knowledge that exists for terrestrial species that have been farmed for thousands of years. Traditional knowledge about AqGR generally concerns

[5] FAO Database on Introductions of Aquatic Species. http://www.fao.org/fishery/dias.

natural history and ecosystem information that, while highly relevant to culture performance, has so far been little used in aquaculture and genetic improvement. Often such knowledge is available in scientific or public sources or appears obvious, e.g. salmon living in cold areas have better cold tolerance than those living in warmer areas (Oleson et al. 2007). Thus, genetic improvement and dissemination of its fruits have generally happened at commercial farms or breeding centres with access to technology and funding (Benzie 2009; Greer and Harvey 2004).

c. Status and trends in exchange

The amount and value of the exchange of living AqGR for aquaculture are difficult, if not impossible, to determine. Data on traded commodities and fish products do not usually differentiate between aquaculture and wild fisheries; nor is a distinction often made between animals exchanged as a genetic resource, e.g. to be bred or improved, or as a commodity, e.g. to be simply grown and consumed. The raw numbers do, however, convey something of the importance of aquaculture: total export in aquatic species (including aquatic plants) and products derived from them reached US $85.9 billion in 2006, and many developing countries are now net exporters of these products. For example, China and nearly all South East Asian and South Asian countries export farmed shrimp. Latin America exported US $1.24 billion worth of farmed shrimp, a commodity that is also the main aquaculture product exported from Sub-Saharan Africa. Although much *Clarias* catfish production is consumed or traded locally in Asia and Africa, processed striped catfish, farmed in Vietnam, is exported to over 100 countries, and the exports in 2007 were valued at US $837 million. The export value of farmed Atlantic and coho salmon from Latin America was US $1.5 billion in 2005. Trade of AqGR in aquaculture represents significant components of national economies and is expected to increase (FAO 2009).

FAO maintains a database on introductions of aquatic species (DIAS[6]; see also Bartley 2006) that can be accessed to examine, *inter alia,* what species have been exchanged among countries for aquaculture purposes. According to DIAS, much of the exchange for the genetic resources examined here has not been from "south" to "north", but in different directions (Figure 2). Although DIAS is a comprehensive source of information on alien species and does demonstrate the interdependence among countries, the database generally only documents the first movement of a species into a new area and therefore is not appropriate for analysing trends. Additionally, the database maintains information only at the species level; movement of genetically altered species, strains and varieties would be useful additions to the database, but at present are not included.

When an aquatic genetic resource is shared by several nations it can be readily transferred and accessed, sometimes without the knowledge of all parties; this has happened with striped catfish, whose range is shared by three nations (Nguyen 2009). National policies on exchange of AqGR within a country can be stringent—in Canada and the United States of America, for example, transfer of salmonid gametes for any purpose is tightly controlled—but in many countries, national policies are less restrictive than international ones. They may even be non-existent. Reasons include a low level of concern for introduced diseases; lack of awareness of ecological issues, including differences between watersheds within a country; difficulties in enforcement; and a desire to stimulate trade. Thailand, for example, forbade export of shrimp seed or broodstock in order to protect the local industry. There are some restrictions on accessing wild stocks; Australia, for example, has seasonal closures that prevent harvest of marine shrimp in order to protect the stock during spawning. There have also been measures to restrict harvesting of wild shrimp post-larvae in Bangladesh (Benzie 2009). Reserves have been established to protect oyster (*C. arienkensis),* catfish, marine shrimp and other aquatic resources in China. Future ABS protocols may impact the exchange of AqGR by increasing the cost (both in terms of time and money) of acquiring resources (see section III).

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[6] http://www.fao.org/fishery/dias.

3. Benefits of use and exchange of AqGR

The use and exchange of AqGR have contributed significantly to the global success of aquaculture. Because of their high intrinsic potential for adaptation and diversity of farmed species, industry has been able to expand, respond to consumer preferences, and maintain production after loss from disease. Examples include tilapia, which has become a food security staple in Asia, and is widely marketed around the world appearing in grocery stores and on the menus of restaurants from Germany to Japan. Indeed, the freshwater fish species that is imported to the United States of America in highest quantity is tilapia, almost all of which is cultured in areas beyond its natural range. Common carp varieties with different colours, shapes and environmental tolerances allow this species to be farmed in a wide variety of environments and farming systems, and to satisfy different consumer tastes. Common carp has also been used in ornamental culture (koi carp) (Jeney and Zhu 2009).

Shrimp farms in areas devastated by disease were able to continue production by switching to more disease-resistant species and varieties, associated with the introduction of better management practices. The domestication of species such as the white-leg shrimp, and the development of SPF shrimp have reduced reliance on wild shrimp species, such as black tiger prawn, that had significant disease problems. In Japan, use of alien shrimp species that had lower protein requirements than native Kuruma prawn, *P. japonicus,* enabled farmers to improve production and reduce costs and reliance on fish meal (Benzie 2009). In a final example, importing non-native oysters to the Pacific coast of North America and Europe has allowed for continued production and economic gain after native species declined due to disease and habitat degradation (Guo 2009). Pacific oysters are in fact preferred over native oysters by consumers in many areas, and are more cost-effective to produce.

a. Food security and poverty alleviation

Aquaculture provides both direct and indirect food security and poverty alleviation. The world's population is expected to reach 9.3 billion by 2050, with most of this increase projected to be in developing countries. In many developing countries, fish provide a significant source of high quality animal protein. Common carp and tilapia, for example, provide local food security to small-scale and rural communities as well as export opportunities for larger-scale commercial farms. In many cases, poverty is reduced and food security increased through the economic activity that aquaculture brings to communities. In some cases, the product is not consumed locally: people may not eat a farmed salmon, but will use the earnings from working in salmon facilities to purchase food and other necessities. In others, the effect is more immediate: for example, much of the hybridized *Clarias* catfish in Thailand and Vietnam is traded and consumed locally. Although, there is some regional trade in *Clarias*, the species is not considered a high value export commodity. However, most of the striped catfish produced in Vietnam is processed and exported to over 100 countries. Here, the significant impact of the processing industry, which employs large numbers of rural women (around 120,000 to 150,000), is clearly seen (Nguyen 2009).

b. Incentives for conservation

Reliance on wild stocks for aquaculture commodities (marine shrimp, oyster, tilapia and common carp are examples) provides an incentive to conserve those resources and to provide reservoirs of genetic diversity for future use. For some commodities, price reduction due to increased aquaculture supply has made commercial fishing less profitable, leading some fishers to leave the sector. Pacific salmon is an example, where farmed Atlantic salmon are readily available in the market and profits from fishing are declining, although the situation is complicated by the fact that the cultured species is a European import and there are many other reasons for the declining returns on fishing effort (Greer and Harvey 2004).

Aquaculture can provide alternatives to harvesting wild resources. Groupers are an emerging aquaculture species group for the highly profitable live-fish market. The wild fishery often uses poisons and explosives to harvest fish from coral reefs; breeding and farming groupers would provide an alternative to destructive fishing practices (Nguyen et al. 2009). The increased efficiency of food conversion in domesticated farmed fish has led to reduction in fish meal and oil in commercial diets, thus lowering the dependence of the sector on wild forage fishes.

c. Commercial benefits

The commercial benefits from aquaculture are easily demonstrated. Aquaculture provides both commercial and food security benefits to developed and developing countries. The global aquaculture production of aquatic animals in 2006 was valued at US $78.8 billion.[7] Per capita supply from aquaculture has increased from 0.7 kg in 1970 to 7.8 kg in 2006 and now accounts for nearly half of all food fish consumed. The production values of the six commodities in this report are listed in Table 2.

Table 2. Value and quantity of selected aquaculture commodities in 2006 (FAO Fishstat Plus)

Species group	**Value (1000 US$)**	**Quantity (t)**
Common carp, *Cyprinus carpio*	2,706,879	2,822,125
Salmonids (*Oncorhynchus* spp. and Atlantic salmon, *Salmo salar*)	9,804,409	2 ,095,493
Nile tilapia, *Oreochromis niloticus*	2,107,411	1,889,277
Tropical catfish, *Clarias spp*	422,314	333,809
Striped catfish, *Pangasianodon hypophthalmus**	645,000	683,000
Marine shrimp, Penaeidae	12,398,316	3,108,730
Oysters, *Crassostrea* and *Ostrea spp*	2,916,158	4,257,606

* 2007 data for Striped catfish are from Sub-Institute for Fisheries Economics and Planning in Southern Vietnam, 2009. Project on development planning for catfish production and consumption in the Mekong Delta up to 2010 and strategic planning up to 2020. Department of Aquaculture, Ministry of Agriculture and Rural Development Ho Chi Minh City, Vietnam, 124 pp (in Vietnamese), cited in Phan et al., 2009.

4. Conclusions

a. Domestication or genetic improvement is key to increased production

Key factors in the growth of aquaculture include domestication (or at least the ability to breed animals for multiple generations), genetic improvement from the use of genetic technologies, development of disease free stocks and reduced reliance on wild AqGR. Table 3 summarizes the status of the genetic resources covered by the background papers and reveals that there is a range within and among the species groups in terms of how AqGR are used, the level of domestication and reliance on wild relatives.

[7] This figure represents farm-gate value and is not the same as the US $85.9 billion value of fishery exports as not all aquaculture production is exported.

Table 3. Summary description of selected species groups. Degree of domestication ranges from 0 for no captive breeding to 10 for highly domesticated species. Production systems are P = ponds, SP = small ponds < 0.3 ha, C = cages, F = various structures in natural environment, e.g. racks, bags, and long-lines; Genetic technologies are B = breeding, SB = selective breeding, GT = gene transfer, H = hybridization, MS = mono-sex production, P = polyploidization; Dependence on wild relatives ranges from 0 for no input to 10 for complete reliance on wild species.

Species Group	Approximate degree of domestication (range 0-10)	Main production system(s)	Genetic technologies used	Approximate dependence on wild relatives (range 0-10)
Common carp	9 (range 3-10)	P	SB	3 (range 0-7)
Pacific and Atlantic salmons	7 (6 – 8)	C	SB, GT*	1 (1-4)
Nile tilapia	6 (5 – 7)	C,P	SB, H, MS, GT*	2 (1- 4)
Clarias spp and striped catfish	4 (1 – 5)	C,P,SP	B, H	3 (2-8)
Marine shrimp	6 (0 – 8)	P	B, SB	2 (1-10)
Oysters	5 (0 – 7)	F	B, SB, P	3 (2-10)
Emerging species	1 (0 – 3)	Varied	B	8 (7-10)

* Gene transfer has been accomplished, but no GMOs are available commercially.

Historically, additional markets have developed once mass quantities of healthy animals could be produced, transported and exchanged. This helped aquaculture become the fastest-growing food production sector.

b. Exchange of AqGR

Every commodity examined in this report is farmed in areas both within and beyond its natural distribution. In the cases of marine shrimp and tilapia, domestication and genetic improvement took place in facilities outside the species' natural range. The use of alien species and non-native stocks has thus contributed to the growth of the sector and provides food security and economic opportunity. However, in response to threats from introducing pathogens with imported AqGR and from unknown ecological impacts from alien species, development of national broodstock and indigenous species is being undertaken.

For many of the most genetically improved resources covered here, the exchange of useful genetic resources has not been from "south" to "north", as in the plant sector. The pattern of exchange of AqGR demonstrates the recent development of the industry, in that traditional knowledge and the associated breed development and improvement is more scarce (or at least less well documented) than for terrestrial agriculture, and a degree of technology is required to breed and genetically improve aquatic species. For example, very large amounts of money (US $50 million) were spent on developing domestication technology for marine shrimp in the United States of America, which was then exported to developing countries (Benzie 2009).

c. Interdependence

There has been substantial interdependence among countries, businesses, and farmers, i.e. providers and users, for exchange of aquatic genetic resources. Northern hemisphere salmonids have been moved to the southern hemisphere, Norwegian Atlantic salmon are exchanged with companies in Europe and Britain, and there is some transfer of salmonids, via development projects, to tropical highland areas in Nepal, Sri Lanka, Thailand, Vietnam and Bhutan (Solar 2009). Marine shrimp from the Americas provide resources to companies in Asia (Benzie 2009). Most countries involved in aquaculture receive imports of AqGR for specific commodities.

Common carp provides an example where international exchange may in fact be less important. This species was moved to so many areas that today there is little need for exchange apart from improved breeds (Jeney and Zhu 2009). With the trend toward developing local broodstock in order to avoid disease issues, interdependence may diminish for certain other commodities such as salmon. Some countries are becoming increasingly reluctant to share genetic materials with other countries that are potential trade competitors. For example, Cambodia and Vietnam are restricting exchange of striped catfish for breeding purposes (Nguyen 2009).

In the current state of affairs in most developing countries, hatchery management in general, is conducted in a very *ad hoc* manner where little attention is paid to genetic factors. Consequently, it is not uncommon for recipient countries to request replenishment of genetic resources from donor countries on a regular basis (e.g. China re-introduced bay scallops from the United States of America and Canada, Bangladesh requested replenishment of striped catfish broodstock from Thailand and Vietnam requested broodstock from Cambodia as a result of the deterioration of the performance of the original stocks). In the case of common carp, the species has been domesticated and distributed for so long that exchange is an established pattern of use; ownership of breeds is not an issue (Jeney and Zhu 2009).

d. Is underutilization or over-utilization a cause of genetic erosion?

For most farmed species, genetic erosion is not yet an issue because of the relatively recent development of aquaculture and improved breeds. Due to the relative scarcity of genetically differentiated strains that were developed in the past, the use of popular species or strains today has not caused significant genetic erosion. Some unused common carp varieties are at risk of being lost, but this is an unusual situation. Some species of tropical catfish are not being farmed because modern hybrids perform better. In Australia, widespread use of Pacific oysters, combined with their more rapid growth rate, has led to competition in the market, and in nature with native Sydney rock oysters. Additionally, because Pacific oysters are more lucrative to farm, there is less incentive to farm native species in many areas.

CHAPTER III: Current practises in exchange of AqGR

1. Current terms and modalities for exchange of AqGR

a. Availability of AqGR

Aquatic genetic resources of use in aquaculture are available in gene banks of both living and frozen material, and in private commercial aquaculture facilities. Live gene banks that are publicly financed (i.e. government or private/public partnerships) are generally only available for a few of the most commonly used species in aquaculture. Extensive collections of common carp varieties exist in China, Hungary, Poland, and Russia (Jeney and Zhu 2009). In Germany no centralized living gene bank exists, but local carp farmers maintain useful varieties for propagation and grow-out, and can sell improved varieties if they participate in a government sponsored programme to maintain the improved varieties. In China, the government owns the carp genetic resources and farmers can only distribute through approved extension channels. The Government of Thailand maintains a few pure stocks of *Clarias macrocephalus* with no specific regulations on their use or release; generally they are only available for research upon receipt of a formal request from the researcher (Na-Nakorn and Brummett 2009).

Collections of frozen AqGR are often sponsored by government agencies more as a conservation measure to protect against complete loss of the resource from the wild than as a resource for aquaculture (Harvey et al. 1998). The Department of Fisheries and Oceans (DFO) in Canada maintains limited collections of frozen sperm from species of Pacific salmon, many runs of which are declining (Solar 2009). Frozen sperm banks for the Thai catfish, *Clarias macrocephalus,* are held by the Thailand Department of Fisheries, but there are no guidelines or policies on access of this material for either research or commercialization (Na-Nakorn and Brummet 2009).

National governments may maintain collections of useful aquaculture species in order to help promote local aquaculture interests or for foreign trade. The Government of Viet Nam set up hatcheries and a dissemination system to help distribute striped catfish to the aquaculture industry (Nguyen 2009). A commercial grower of Arctic charr in Canada used brood stock derived from government collections and a government breeding programme helped increase production of this species in Iceland (Solar 2009). The Government of Bangladesh has requested live striped catfish from Thailand to restore genetic diversity in its farmed stocks, however action on the request is still pending. Similarly it has been suggested that Cambodia may restrict further export of striped catfish if Cambodian aquaculturists want to start farming the species (Nguyen 2009).

Commercial aquaculturists farming major commodities, e.g. salmon, carp, oysters and shrimp, maintain the vast majority of genetically improved and domesticated stocks (as opposed to government collections). For example four companies have Atlantic salmon breeding programmes in Norway, three are in Canada, three in Chile, and one private breeding company exists in Ireland, Scotland, Australia and Iceland (Solar 2009).

Although extensive collections of AqGR exist in both public and private facilities, there are no generally accepted protocols or regulations governing the access to and use of these resources. Private law contracts are usually agreed between the providers and users of the resource and very little importance is given to access and benefit sharing considerations. Private aquaculture groups exchanged striped catfish from Cambodia to Viet Nam, and from Thailand to numerous Asian countries. Sales contracts were established with no regulations in place to control such movements. Recently private sector contracts provided female striped catfish from Cambodia to Viet Nam to improve the genetic resources of the Vietnamese stocks (Nguyen 2009). There has been substantial movement of striped catfish among countries of the lower Mekong River with no systematic policy on access and exchange in the region (Nguyen 2009). One hundred twenty eight bay scallops, *Agropecten irradians,* where introduced from the USA to China in 1982. Although only 26 of these animals survived, the introduction lead to an extremely productive aquaculture industry based on the exotic species. There were no concerns about access or returning benefits to the USA and after several years more scallops were introduced from the USA and Canada to counteract inbreeding in the Chinese stocks and increase production (Guo 2009)

There are a variety of practices on how the aquaculture industry exchanges AqGR and thus a variety of potential mechanisms to regulate the exchange. The practices depend on the level of domestication of the species and on how production is divided into broodstock development, collection of seed, and grow-out, and on perceived risks or benefits from the exchange. For marine shrimp (Benzie 2009) and Atlantic salmon (Solar 2009) genetic resources are improved by private breeding companies and then the genetically improved stocks are “multiplied” by other hatchery facilities in order to provide enough animals to sell to farmers for grow-out. The multiplier facilities may enter into legal contracts or material transfer agreements (MTA’s) with the breeding companies that set restrictions on how the multiplier hatcheries may use the genetically improved stocks. Similar multiplication facilities are used in production of other species, e.g. tilapia (Eknath and Hulata 2009).

Material transfer agreements (Box 2) are one way of specifying the conditions for exchanges of genetic material. To protect breeders’ investments in improving stocks, MTAs are often drafted to prevent multiplier stations or grow-out facilities from selling the stock for breeding purposes without compensation and recognition of the breeders from which the stock was acquired. For exchange of GIFT tilapia, MTAs were established to help ensure proper maintenance of the breed and its proper identification, and to control further dissemination of the improved tilapia (Box 2). In general the MTAs used in the dissemination of GIFT were effective. However, unauthorized sales and use have been observed, e.g. the GIFT tilapia was imported to African countries when such importation was contrary to national policy and the MTA, and unauthorized movement of Atlantic salmon from Norway occurred (Oleson et al. 2007).

However, commercial contracts between supplier (breeder) and user (farmer) may not always include restrictions on how genetic material may be used. Atlantic salmon in Norway is legally available from private or public breeding centres for grow-out or propagation to any buyer (Olesen et al. 2007). Norway is developing legislation governing access to wild Atlantic salmon that maintains that Norwegian genetic resources are common property available to all to use except when intellectual property rights, e.g. patents, have been established on the resource. The tracking, enforcement and control of contracts from a legal standpoint were seen by Norwegian aquaculturists as more effective mechanisms to ensure fair access and prevent unauthorized exchange of genetic resources than patenting.

Often policies on exchange are ineffective and hard to enforce. In light of the facts that there are numerous group involved in the production process, from breed improvement to sale of live fish, and that most genetically improved aquatic species are fertile and can be easily reproduced, there is substantial scope for failure to adhere to MTA’s and for the illegal or unauthorized exchange of AqGR. Shrimp farmers have often taken shrimp from grow-out ponds and used them as breeding material on an *ad hoc* basis (Benzie 2009). Norwegian breeding companies initially prohibited the export of genetically improved Atlantic salmon (Oleson et al. 2007), but then in 1998 began to promote and organize the export in response to an extensive export of material that was already occurring. The situation is exacerbated by the rapid growth of aquaculture of some species and prospects of immediate financial gains. For example, initially the exchange and use of SPF shrimp followed MTA’s, and genetic and fish health considerations, but increased demand and a shortage of genetically improved seed lead to relaxing of exchange protocols and an increase in illegal activity such as unauthorized collection of wild stocks and movement of shrimp of unknown disease or genetic status (Benzie 2009).

BOX 2: Suggested Components of a Material Transfer Agreement[8]

The recipient of AqGR agrees:

- to abide by the provisions of the Convention on Biological Diversity and the FAO Code of Conduct for Responsible Fisheries;
- to preclude further distribution of germplasm to locations at which it could have adverse environmental impacts;
- not to claim ownership over the material received, nor seek intellectual property rights over the germplasm or related information;
- to ensure that any subsequent person or institution to whom they make germplasm available is bound by the same provision;
- that the responsibility to comply with the country's biosafety and import regulations and any of the recipient country's rules governing the release of genetic materials is entirely its own;
- to follow quarantine protocols; and
- to abide by the principles in The International Code of Conduct for Plant Germplasm Collecting and Transfer * in cases where germplasm is transferred beyond the boundaries of the country.

* http://www.fao.org/ag/agp/agps/pgr/icc/icce.htm; although this code is not specific to AqGR, the basic principles can be applied to other sectors.

2. Effects of legal or technological restrictions on use and exchange of GR

a. ABS issues

ABS issues have not been a major consideration in restricting the use and exchange of AqGR. Most national policies on exchange and use of AqGR are much more concerned with quarantine, aquatic animal health issues and the risks of adverse environmental impacts. In general policies regulating such access and benefit sharing are scarce but some examples do exist (see below). It is often unclear who has authority of natural resources especially in areas where indigenous people and national governments may have joint management responsibilities (Greer and Harvey 2004).

Access to wild genetic resources is often necessary for establishing a genetically diverse breeding group, for increasing the genetic diversity of established aquaculture species or for simply acquiring animals to farm or breed when hatchery systems are not established, e.g. as in the case of farming new species. Whereas access to farmed stocks or those in gene banks is usually controlled by contracts or similar agreements, access to wild AqGR is often determined by government agreements, fishing regulations, and consent of local communities, and may be extremely complicated (Nguyen et al. 2009). The Consultative Group on International Agriculture Research (CGIAR 2001) produced guidelines on acquisition and transfer of genetic resources to comply with Article 15 of the CBD. The guidelines state that access be granted only if there is:

- mutually agreed terms;
- prior informed consent; and
- permission from government in the form of legal documents.

In general the above elements have not been incorporated into national legislation and countries may not have adequate policies in place to implement the guidelines. Canada has in some areas enacted agreements and legislation on access to wild aquatic genetic resources that considers the rights of indigenous people. The Canadian DFO requires that those seeking access to genetic resources have a scientific collection permit from DFO, authorization from the federal or provincial government if the

[8] From the International Network for Genetics in Aquaculture (INGA) www.worldfishcenter.org and Bartley, et al. 2009.

genetic resource is to be moved out of the watershed, and that indigenous people be consulted (Greer and Harvey 2004).

In the Northwest Territory of Canada policies are more developed and the Department of Fisheries and Oceans requires prior informed consent for access to and use of AqGR for fishing, research and aquaculture. A private company seeking to develop improved strains of Arctic Charr sought to access a total of 14 genetically distinct stocks from several indigenous communities. The private company offered each community 5% equity in the new company that would farm the improved stocks. Other non-monetary benefits would be education on breed improvement, practical experience in fish farming and access to improved stocks when they were developed. Although the original 14 groups would be owned by the communities, any improved stocks originating from cross-breeding them would be the property of the private company. Approval for the program was needed from each community, the DFO, and the territory's wildlife management board. Most of the indigenous communities reacted unfavourably to the programme (see section IV for perspectives). As a result, all but one of the communities refused access to their genetic stocks. In this example, the local communities had well defined and recognized rights over access to the resource.

For newly developed or emerging species access and exchange often follow a pattern of collection of wild material then developing hatchery technologies as in the case of the striped catfish in Viet Nam and the Mekong River region. Because hatchery technology and production of larvae were not well established, tremendous amounts of catfish larvae were collected from the wild: 800 billion larvae from Viet Nam were collected in 1977 and 165 billion from Cambodia in 1981 and then transferred to Viet Nam. In 1994 Cambodia banned the collection of wild catfish larvae and Viet Nam followed in 2000. Now larvae must originate from hatcheries, although some broodstock may still be sourced from the wild. Formal access to wild resources required fishing permits and the genetic resource was treated similarly to a fishery resource. For marine species that are emerging as aquaculture candidates in the Life Food Fish Restaurant Trade (LFFRT), access to wild fish that will serve as future broodstock often requires fishing licenses and fishers must follow size restrictions as if they were involved in capture fisheries. (Nguyen et al. 2009).

b. Other restrictions

Legal restrictions in the form of national legislation or business policies do not appear to have hindered the development of aquaculture. Many national ministries with responsibility for agriculture, aquaculture, fisheries and economic development are not presently familiar with the Convention on Biological Diversity's articles on access, benefit sharing and exchange of AqGR. Material transfer agreements are not usually provided for in official national policy, but could help ensure responsible exchange of AqGR and prevent exchange of resources to areas where they may have adverse impacts.

The main considerations in restricting the movement of AqGR are aquatic animal health and environmental impacts. Numerous countries and regional groups such as the European Union have strict legislation, guidelines and diagnostic procedures to prevent the spread of aquatic animal pathogens (AFS-FHS 2007; OIE 2009; Jeney and Zhu 2009). For example, shellfish imported into the United States of America must be certified as disease free and often must come from an approved region that does not have specific pathogens. The spread of disease in the shrimp and salmon farming sectors has provided motivation to restrict the import of fish and eggs (Benzie 2009; Solar 2009). Similarly many countries have enacted legislation or policies restricting the movement of alien species. China initially promoted the introduction of a wide variety of aquatic species for fisheries and aquaculture development and marine shrimp and bay scallops are examples of very successful introductions for aquaculture in China. However, in light of concerns for potential adverse environmental impacts, importation of alien species is more tightly regulated (Guo 2009). The introduction of a Chinese oyster to the eastern United States of America in order to provide a fishery product and ecosystem services that the native oyster could no longer provide was recently rejected because of fear that the species could endanger native biodiversity (Guo 2009). In some instances, specific aquaculture species have been labelled as "invasive" e.g. common carp in Australia and Nile tilapia in parts of the United States of America (California Code of Regulations 2009), and exchange and use have been prohibited in specific areas.

The greatest technological restriction on the exchange of AqGR is the fact that cryopreservation is normally only practical for the male gametes of fish species and for some mollusc larvae. Apart from this limitation, there are few other technical restrictions on the exchange of resources; early life history stages and even adult animals can easily be transported over long distances (Harvey et al. 1998). Regional breeding networks are not constrained for technical reasons, but usually for political, commercial or research constraints (the Shrimp Genome Sequencing Consortium and an industry-wide consortium in Colombia are exceptions).

3. Conclusions

a. Are current practices sufficient?

Current practices may not have addressed ABS issues primarily because:

- ABS issues are not well enshrined in national, regional or international policies;
- they are not a priority for regulators nor for the industry (see next section); and
- existing policies and private law contracts appear to work reasonably well.

However, current practices have for the most part allowed aquaculture to develop into a global activity that provides food and economic benefits to millions of people in both developed and developing areas. There has been very little erosion of farmed aquatic animal diversity, not unexpected given the relative scarcity of long-standing traditional breeds of aquatic species. The most serious impact on farmed species from the exchange of AqGR has been the transmission of pathogens to new areas, with often devastating losses to aquaculture production and the potential for transfer to wild species. Restrictions on access to wild/foreign stocks may be expected as countries become reluctant to introduce them for fear of introducing pathogens.

There are mechanisms to prevent introduction of invasive alien species and potential pathogens, but they are often not followed because of lack of awareness or political will. Even in instances where adequate regulations and quarantine rules do exist, lack of awareness and enforcement have still permitted wide-spread losses from introduced diseases, especially in salmon and shrimp aquaculture.

Once a non-native species becomes a viable economic commodity, regulations are often put into place to protect the resource and the industry. Pacific oyster is a good example, having established large commercial farming areas and naturalized populations in North America. There are now import restrictions on Pacific oysters in many coastal regions of North America, created to reduce the risk of introducing disease to a species that was itself introduced more than seventy years ago. The species has in effect become officially “adopted”; most North Americans would in fact be surprised to hear that their Pacific oyster is not native. Importation of Pacific oysters in most areas in North American currently is not from the species’ native range, but from areas, both local and foreign, where the oyster was introduced and can be certified as “disease free” (Guo 2009).

b. What policies or practices promote or hinder the responsible exchange of aquatic genetic resources?

Except in a few instances, e.g. Arctic charr in Canada and GIFT tilapia, international regimes on ABS for AqGR have not been implemented at the national level or for regional economic groups. However, there are sector specific policies that relate to the exchange and use of AqGR, although ABS concerns are notably absent. Policies need to reflect not only the value of aquaculture and the need to exchange AqGR, but also the need to protect the environment and the aquaculture sector through responsible exchange of AqGR. At the intergovernmental level, these principles have already begun to be incorporated into policy. The CBD and the FAO Code of Conduct for Responsible Fisheries (CCRF) (FAO 1995) promote both use and conservation of AqGR, and have already led to development of a number of non-binding international protocols and guidelines that support these principles. For example, the CCRF in regards to aquaculture calls for:

- the responsible development and management of aquaculture, including an advance evaluation of the effects of aquaculture development on genetic diversity and ecosystem integrity, based on best available scientific information (Article 9.1.2);
- the conservation of genetic diversity and maintenance of the integrity of aquatic communities and ecosystems by appropriate management (in particular to minimize adverse impacts from non-native and genetically altered species) (Article 9.3.1); and
- the adoption of appropriate practices in the genetic improvement of broodstock (Article 9.3.3).

Technical Guidelines for Responsible Fisheries in support of genetic resource management in aquaculture (FAO 2008) include technical and policy information on, *inter alia*, broodstock management, genetic improvement, dissemination of improved breeds, risk assessment, gene banking, and a precautionary approach. A precautionary approach (FAO 1996) contained in the guidelines recommended that:

- reference points be established to indicate when action is needed to address undesirable impacts from aquaculture;
- contingency plans are in place in the event that reference points are reached and the action taken is agreed upon by stakeholders in advance;
- preference should be given to conservation and maintenance of the productive capacity of the resource;
- impacts should be reversible within one human generation; and
- the burden of proof should be in accordance with the above and the standard of proof be commensurate with expected impacts.

Application of the precautionary approach to the exchange of AqGR in aquaculture has not, however, been common.

In another example, the ICES Code of Practice on the Introduction and Transfer of Marine Organisms[9] describes a framework to allow decision-makers to evaluate the likelihood of an introduction's producing the desired beneficial impacts, and to avoid or minimize adverse impacts. The Code has been adopted in principle by the regional fishery bodies of FAO for both marine and inland aquaculture and follows a precautionary approach to species introductions. At present, most guidelines indicate that movement of genetically differentiated strains should also be subject to these guidelines. Because of the lack of genetic data on the strains and difficulty in monitoring and enforcement, little emphasis is placed on managing exchange of genetic material in most countries.

At the national level, progress has been limited, although there are encouraging signs. The Technical Guidelines (above) on the management of genetic resources in aquaculture have been developed to assist national resource regulators and policy-makers, and aquaculture farmers have begun to develop best management practices for using and exchanging AqGR. The process of setting standards, creating policy and legislation and applying and enforcing the new regimes will be a long one, and needs to involve industry, scientific experts from government and academia, national and state fisheries and environment agencies, indigenous communities and relevant non-governmental organizations. To date, policies have not addressed access and benefit sharing, except in rare instances (Boxes 1 and 2).

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[9] http://www.ices.dk/pubs/Miscellaneous/ICESCodeofPractice.pdf.

CHAPTER IV: Stakeholders' views

1. Perceptions, awareness of users and providers on access and benefit-sharing in general, including sector-specific policy initiatives

Access and benefit sharing issues do not seem to be a major concern at present for the exchange and use of aquatic genetic resources in aquaculture. Many Norwegian aquaculturists maintain that ABS regimes, including protection of intellectual property, are not useful now in Norway because they are extremely complicated and costly to implement and enforce. However, Norwegian legislation is considering how to provide access to AqGR for breeding and breed improvement while also allowing fish breeders rights to benefit from their labours (Oleson et al. 2007). Divided opinions on ABS were also expressed by the Crucible Group (2001) that felt that ABS laws my lead to unrealistic expectations of reward, but that a ABS regime may at least provide some benefits to local communities or indigenous people. For the genetic resources included in this study, workshop participants and the review papers noted that few user groups have expressed the feeling that benefits had been denied to providers of genetic resources or that access restrictions prevented development of the sector.

Most regulations addressing the transfer of AqGR to date have been designed to protect receiving countries, for example, from disease and environmental harm. In contrast, ABS measures tend to focus on the provider or source countries. A 2002 study, undertaken by World Fisheries Trust for the Convention on Biological Diversity (Word Fisheries Trust 2002), examined 52 national Biodiversity Strategy and Action Plans, "did not uncover significant evidence of national concern over access to national aquatic genetic resources." This observation still holds in many cases; for example, no concern has been raised regarding the use of African catfish to produce the hybrid that is the basis of Thai *Clarias* aquaculture. *Clarias* is widespread in Africa and considered a common property resource (Na-Nakorn and Brummett 2009), just as common carp is considered a common property resource in many parts of Asia and Europe (Jeney and Zhu 2009).

Nevertheless, the need for countries to prepare for access and benefit concerns seems inevitable. ABS issues are beginning to be raised, particularly where the value of AqGR is increasing, (for example, as a result of genetic improvement as summarized in Table 1). One of the most valuable capture fishery resources is bluefin tuna. Currently, the species can not be commercially bred in captivity, but because of its popularity, its wide geographic range and the fact that fishery stocks are declining, efforts to farm the species have been undertaken in Australia, Mexico and the Mediterranean at considerable expense. A company in Australia has raised $58 million since 2005 to work on captive breeding with some success at producing juveniles[10]. It can be expected that efforts to collect wild bluefin tuna for spawning will increase as hatchery production technology improves. At present access bluefin tuna is regulated by regional fishery management organizations, but the situation could change as bluefin become a genetic resource rather than a fishery resource. In another example, Atlantic salmon genetic resources originating in Norway have been moved to Chile and many other countries where they have been used to establish competing industries. Norway is now considering legislation to govern access and benefit sharing regarding these resources (Oleson et al. 2007). The Norwegian legislation seeks means to capture the value of improved salmon for breeders while still allowing farmers, perhaps in other countries, to raise genetically improved breeds. How this will impact countries that currently grow and reproduce Norwegian salmon is unclear, but it may lead to reduced exchange or higher costs of improved AqGR.

Another notable example concerns the movement of the genetically improved GIFT tilapia back to Africa after its development in the Philippines (Box 1). Although original collections were made with approval of African institutions, the African farmers of Nile tilapia were not included in the discussions. The farmers naturally felt some dissatisfaction that "their" fish was being successfully improved and farmed in Asia while they were denied access to the improved tilapia genetic resources.

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[10] http://business.smh.com.au/business/fishy-tale-one-mans-fight-to-save-tuna-20090707-db2o.html?page=-1.

GIFT fish are being allowed back into Africa now in part due to international efforts of FAO, the WorldFish Center, the Government of Spain and the countries of the Volta Basin in Wetern Africa (Bartley et al. 2009).

The example in northern Canada (Greer and Harvey 2004) illustrates the views often held by indigenous people faced with decisions regarding access and benefit sharing that may come into conflict with other legal rights and traditional respect for nature. Inuit communities control access to aquatic genetic resources based on agreements with the Canadian Government. When Inuit communities entered into negotiations with a private company regarding genetic improvement of Arctic charr for an aquaculture venture, access was not granted to all of the requested wild stocks because of failure to get consent from some of the affected communities. Reasons for their refusal included the concern of local fishers that prices for wild fish would decrease, ownership of future generations of improved charr, the concern that patenting genes or improved strains would reduce benefit sharing, and the belief that altering nature offends the spirit of the fish. The latter belief is strong in many indigenous communities. The charr example illustrates important points that are likely to recur in many future ABS negotiations regarding AqGR: concern about aquaculture development on water bodies traditionally used for generations; respect for nature; and concern about the long-term impacts of aquaculture and ABS arrangements.

For some stakeholders, especially in rural and developing areas, offers of future royalties or other monetary rewards may not be sufficient to convince local communities to grant access. Other non-monetary benefits may actually be more important, especially if they address poverty or other issues important to a community, e.g. education (Greer and Harvey 2004). Hopeful collectors of salmonids in Canada and Nile tilapia in Africa promised to provide donors of AqGR increased capacity to manage fisheries, and training on sustainable fish farming and genetic improvement. Additionally part ownership in the improved stocks and hatchery facilities were offered (Eknath and Hulata 2009; Greer and Harvey 2004). Collectors of ornamental fish in Brazil offered training, technology development and improved marketing of the ornamental fish to local communities that provided the ornamental fish (Greer and Harvey 2004). The communities that are involved in negotiating access rights should also be able to negotiate the benefits that are most appropriate for them.

Access to information, particularly genomics and breeding technology, will be important in future aquaculture development. The private shrimp aquaculture industry has provided access to some genetic resources and related information that would facilitate public research into genomics, reasoning that this openness will benefit the company in the long-term, through encouraging collaborative research efforts (Benzie 2009). Plans to use these resources are currently being developed through the Shrimp Genome Sequencing Consortium and will involve several Asian countries. Information on shrimp molecular genetics such as gene expression and genetic maps has been deposited in public access databases such as *Genbank*.[11]

Concerning access to information, one strategy to compensate Africa for providing the genetic resources that helped create the GIFT tilapia, has been to transfer information on breeding technology to African aquaculturists. The WorldFish Center and the International Network for Genetics in Aquaculture (INGA) have thus conducted training courses to increase the capacity of African farmers to genetically improve tilapia and other cultured species.

2. Initiatives of key players

At present, there are few initiatives directly relating to ABS for farmed aquatic species. The book *Blue Genes* by, David Greer and Brian Harvey (2004) represents a milestone in discussions of ABS for AqGR. Their treatment of broad principles and specific case studies on aspects of conservation, fisheries and aquaculture provide useful insight to the complicated nature of ABS issues and the general lack of concern for them from a variety of stakeholders. Greer and Harvey (2004) have

[11] www.ncbi.nlm.nih.gov/Genbank/.

however, identified some national and regional approaches to ABS. As already mentioned, Norway, the leader in farmed salmon production, is developing legislation governing access to AqGR that will seek to protect wild resources, protect the investment in genetic improvement of farmed species and still allow access. National initiatives in Costa Rica and India include ABS issues in overall biodiversity management laws, and the Philippines and Brazil have enacted specific laws on ABS. As with access to plant genetic resources, countries from the "south" may be reluctant to impose restrictions for fear of losing business and revenue to countries with fewer or no restrictions. Regional groups have been established to help avoid such situations, develop guidelines and consistent approaches to ABS and assist with complex legislation on AqGR. These groups include ASEAN, which has developed the ASEAN Framework Agreement on Access to Genetic Resources, the Andean Pact and its Common Regime on Access to Genetic Resources, and the OAU (African Group) which has developed the African Model Legislation for the Protection of the Rights of Local Communities, Farmers and Breeders and for the Regulation and Access to Biological Resources. To the extent that such agreements reflect the spirit of articles of the CBD, AqGR should be covered. The reality though, is that policies and regulations on the farming of aquatic animals and plants are often developed within several ministries in any given country, so it is critical that the people involved in that process be aware of ABS issues.

The international community has developed the Bonn Guidelines (Secretariat of the Convention on Biological Diversity. 2002) on ABS in order to help ensure fair and equitable sharing of benefits derived from the commercial use of biological diversity. Some of the motivation in developing the advice in the Bonn Guidelines was to protect "southern" countries that provided improved GR for agriculture to "northern" countries. However, this pattern of flow of genetic material has not been the main one with AqGR. Considering AqGR for aquaculture, the exchange has most often been south to south; considering the exchange of improved breeds the exchange has been north to south (Figure 2). As stated earlier, this reflects a lack of traditional knowledge on breed improvement and the fact that knowledge on breed improvement in the aquatic sector has been generated relatively recently by groups with access to technology and funding. There appears to be little concern in the aquaculture sphere that source countries have been deprived of benefits from the commercialization of their AqGR; the economic benefit of aquaculture development from being able to use improved stocks (developed elsewhere) may be seen to be adequate compensation.

A recent inter-regional initiative has been taken between NACA and the Network of Aquaculture Centers in Central and Eastern Europe (NACEE), through the establishment of a consortium on freshwater fish genetics and breeding[12]. This consortium is expected to facilitate better exchange of technologies and to document the extent of use and movement of shared fish genetic resources. Already, steps have been taken to document the available strains of common carp in Europe. The consortium will advise and provide suitable guidance to both donor and recipient countries in future genetic resource exchanges.

3. Conclusions

It is difficult to generalize attitudes toward ABS within a sector that farms many species within several phyla, under many different conditions (Greer and Harvey 2004). In spite of the above initiatives, ABS issues are not now a high priority for the industry or regulators (although they may be for some affected communities). The examples of GIFT or Canadian Arctic Charr are not now representative of the sector in general. It should be remembered that GIFT was an instructive case that involved all the classic elements of genetic resource acquisition, use and exchange at a time when there was no clear international consensus on appropriate protocols. Involving all relevant stakeholders in the process of developing decisions on ABS is one of the key aspects that was omitted from the GIFT Program. The lessons learned from the GIFT experience are profoundly important for the future of the industry.

[12] http://www.thefishsite.com/fishnews/8609/collaboration-on-genetics-and-breeding.

Existing contracts, and national and international guidelines and restrictions on the exchange of AqGR for aquaculture are providing for good growth of the sector. Implementation, enforcement and significantly increased awareness of these guidelines and laws are needed to better protect native biodiversity and facilitate sustainable growth of the aquaculture sector itself.

Although AqGR and aquaculture share some characteristics of terrestrial agriculture GR where ABS regimes are given higher priority, there are substantial differences that must be taken into consideration in any sector specific development of ABS framework or legislation:

- Many farmed aquatic species are genetically similar to the wild forms;
- Genetic improvement of farmed aquatic species is a recent undertaking, so only a small part of current aquaculture production is derived from formal genetic improvement programmes, i.e. many genetically distinct breeds do not yet exist;
- The level of traditional knowledge of AqGR used in aquaculture is not as advanced as it is for GR used in terrestrial agriculture;
- Traditional knowledge about AqGR more often concerns natural populations and natural history rather than specific information that would be useful to a breeder;
- The number of farmed aquatic species is increasing and breeds are not being lost, except in rare cases (e.g. some common carp varieties);
- Wild relatives of all aquatic farmed species still exist in nature, may be endangered or threatened with extinction, and hence the subject of national endangered species legislation;
- Exchange of AqGR has generally *not* been from South to North as appears to have been the case in the crop sector;
- AqGR are often genetically improved in areas outside of their natural distribution and then moved to farming areas by groups that have access to technology and funding, rather than by local farmers slowly improving breeds over long periods of time; and
- Concern for compensation for providing AqGR used in other countries has not yet been widely expressed.

In general, national regulators and users of AqGR in aquaculture are not engaged in the process of ABS development. However, it will be important for stakeholders to become involved now if ABS regimes are to be developed**.** The exchange and wide use of aquatic genetic resources have been important contributors to the recent growth of aquaculture. This trend will continue as breeding technology increases and improved strains become more available and useful. At the same time, there is a current trend in some species to reduce exchange and develop local strains of farmed animals in response to concerns about the spread of disease. This development, while potentially limiting the exchange of some biological material, would increase the need to exchange technology and information, for example in the areas of breeding and genomics (Benzie 2009).

For the industry to continue to grow, it will be necessary not only to maintain access to wild genetic resources, but also to bring new species into culture, and to exchange existing alien or native farmed species that are domesticated and genetically improved in a responsible manner**.** Future ABS regimes need to include participation of the main stakeholders, e.g. aquaculturists, and recognize the need for continued development, use and exchange of aquatic genetic resources and associated information so as not to unduly hinder the growth of the sector.

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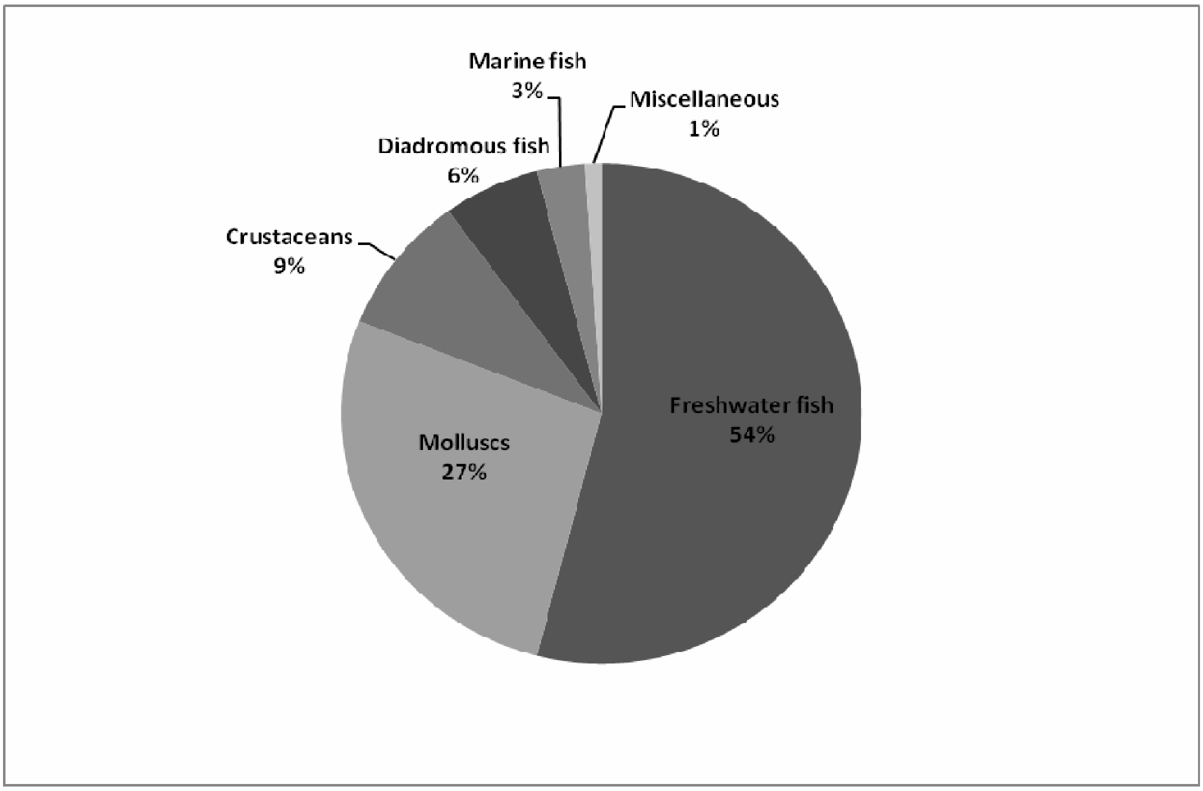

Figure 1. Diversity of aquatic animal species in aquaculture (Source: FAO State of World Fisheries and Aquaculture 2008).

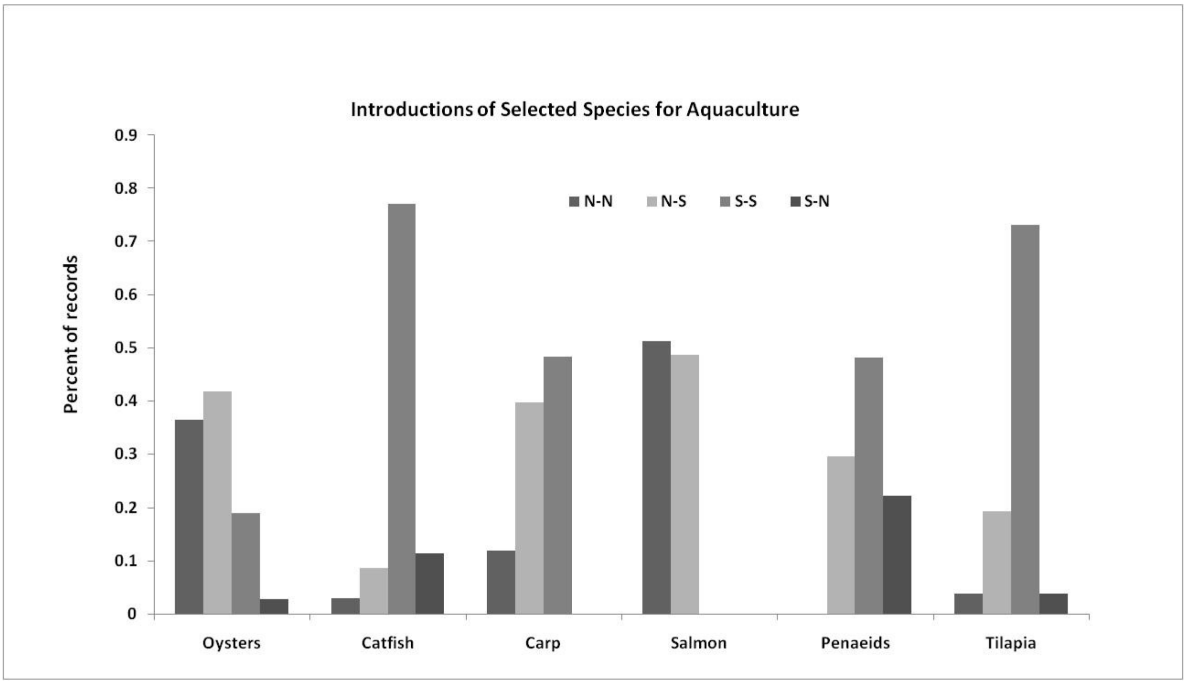

Figure 2. Introductions of selected species groups for aquaculture purposes to and from countries of different stages of development. N signifies "north" or presumably more developed countries and S signifies "south" or developing countries (Source: FAO Database on Introductions of Aquatic Species (http://www.fao.org/fishery/dias)

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