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EDITORIAL

Use and exchange of aquatic genetic resources in aquaculture: information relevant to access and benefit sharing

This special issue of *Reviews in Aquaculture* attempts to compile, for the first time ever, a series of manuscripts on the genetic resources of species/species groups of important cultured aquatic organisms, for food production purposes, and issues related to the use and exchange of these genetic resources. It is important to note that comparable issues on plant and livestock genetic resources have been addressed for over two decades, but aquatic genetic resources have only recently begun to attract the attention of the international community and processes began to be formalized only 2 years ago. In this context we are pleased to present this Editorial in support of these global initiatives and apprise readers of the background issues that have lead to this development.

Concern has been expressed that the current use and exchange of genetic resources for food and agriculture have deprived developing countries of the benefits derived from effective use of their biological diversity. In response, the international community developed the Bonn Guidelines on Access and Benefit Sharing (ABS) to help ensure a fair and an equitable sharing of the benefits derived from the sustainable use of biological diversity (Secretariat of the Convention on Biological Diversity 2002). Taking up the mandate of the World Summit on Sustainable Development the Convention on Biological Diversity is leading negotiations on an international regime on ABS (http://www.cbd.int/abs/regime.shtml).

However, much of the concern over ABS has come from terrestrial agriculture. The papers in this special issue of *Reviews in Aquaculture* reveal that there are significant differences between the aquatic and terrestrial farming sectors. It will be important for aquaculturists to have informed input into future ABS negotiations if sustainability in the sector is to be ensured, and this special publication represents a significant step in providing that input.

The use and exchange of aquatic genetic resources (AqGR) have been crucial elements in facilitating aquaculture to become the fastest growing food producing sector over the past three to four decades. Today aquaculture accounts for nearly half of all food fish consumed and the proportionate contribution is expected to increase as human populations grow and capture fisheries reach their biological limits of production (FAO 2009b). Improvements in aquaculture technology, animal husbandry, nutrition, larval rearing, genetics and breeding have lead to a great diversity of farmed aquatic animals (Fig. 1) and more aquatic species are being farmed today than ever before: in 1950 countries reported farming 72 species from 34 families; by 2006 production was reported for over 336 species from 115 families (FAO 2006).

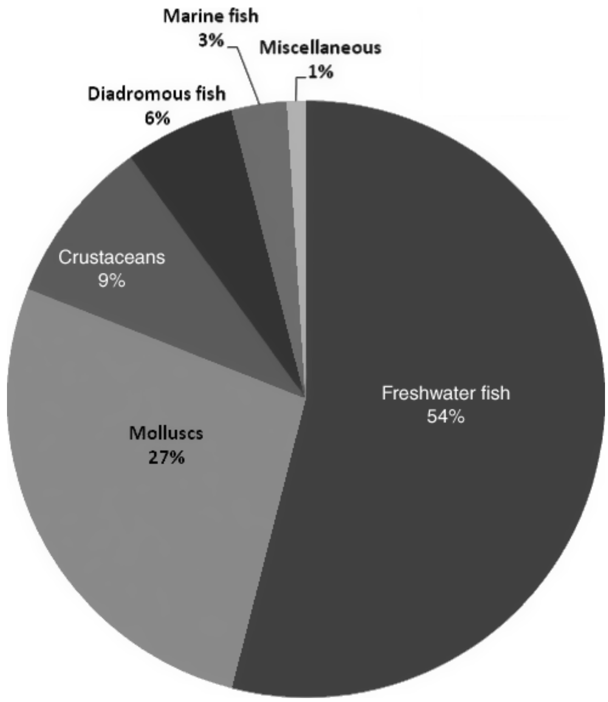

Figure 1 Diversity of aquatic animal species in aquaculture (FAO 2009b).

To determine how the use and exchange of AqGR has influenced production in aquaculture and to inform future discussions on ABS, the papers in this issue examine eight groups of aquatic animals: common carp, Nile tilapia, walking catfish, striped catfish, salmonids, marine shrimp, selected bivalve species and some species that are emerging as important aquaculture commodities. These groups represent important aquaculture species from three major taxonomic groups: fin fish, bivalve shellfish and decapod crustaceans. These groups are well established as farmed species in both tropical and temperate areas in developed and developing countries, have been domesticated to varying degrees, are widely exchanged either internationally or regionally, are grown in a variety of production systems, represent the range from small to large scale aquaculture and depend to differing degrees on wild genetic resources. In addition, a range of genetic technologies has been used to increase their production.

The papers in this issue describe a variety of uses of AqGR that include breeding and genetic improvement in aquaculture, supporting culture-based fisheries (Solar 2009), providing bait fish (Na-Nakorn & Brummett 2009) and producing ornamental species (Nguyen *et al.* 2009). Gjedrem (2005) estimated that only ~5–10% of all aquaculture production is derived from systematic breeding programs and the papers here reflect the diversity of genetic technologies that have been used to improve production. Captive breeding, selective breeding, hybridisation and chromosome set manipulation are shown to have been used to varying degrees to increase production and profitability in the species examined in this issue. Gene transfer is expected to be a technology that may soon have commercial application in the production of salmonids (Solar 2009).

Aquatic species are amenable to genetic improvement and domestication as soon as the life cycle has been closed in captivity. However, the life cycle has been closed only recently for most farmed aquatic species. The common carp is the notable exception, with breeding and domestication beginning approximately 2500 years ago (Balon 1974). More breeds and improved strains have been produced for common carp than for any other species (Jeney & Zhu 2009); for all other species, controlled breeding has been a relatively recent activity.

Substantial improvement in production from simply farming a species that can be bred in captivity was demonstrated by Benzie (2009) for marine shrimp. Farming of the white-leg shrimp *Penaeus vannamei* Boone, 1931 for which hatchery breeding is possible, accounts for ~60% of all marine shrimp production and has surpassed the production of the previously top-producing species, the giant tiger prawn, *Penaeus monodon* Fabricius, 1798 which still relies heavily on the collection of larvae or broodstock from the wild. Similarly, the rapid increase in the production of striped catfish (Nguyen 2009) in Vietnam demonstrates how fast markets can grow for emerging species that are easily reproduced.

Selective breeding is a long-term genetic improvement strategy that has been shown to be important in a few species of marine shrimp (Benzie 2009), common carp (Jeney & Zhu 2009), Nile tilapia (Eknath & Hulata 2009), bivalve molluscs (Guo 2009) and salmon (Solar 2009). Selective breeding allows further changes to the selection criteria. For example, selection in Atlantic salmon in Norway focused initially on improving the growth rate and then added age at maturity, disease resistance and carcass quality (Solar 2009). The production of common carp strains that have improved growth and that can meet consumer demands for morphology and different colour patterns has relied on selective breeding and intraspecific hybridization of genetically differentiated strains or populations (Jeney & Zhu 2009).

Na-Nakorn and Brummett (2009) demonstrated that interspecific hybridization is a rapid way to improve production without embarking on a long-term selective breeding program. Hybridization between the Thai catfish *Clarias macrocephalus* Günther, 1864 and the African species *Clarias gariepinus* Burchell, 1822 combines the desirable flesh quality of the Thai species with the fast growth rate of the African species. These hybrids constitute ~80% of Thai catfish production. Although crosses between Nile (*Oreochromis niloticus* Linnaeus, 1758) and blue (*Oreochromis aureus* Steindachner, 1864) tilapia yield all-male (or mostly male) offspring that have growth advantages over mixed-sex offspring (Eknath & Hulata 2009), interspecific hybridization did not play a significant role in the production of the other species groups examined in this issue.

Because triploids do not devote much energy to producing gonads or secondary sexual characteristics, more energy is available for growth. The production of triploids has been shown to be useful for improving growth, meat quality and disease resistance in common carp (Jeney & Zhu 2009). However, in other species the growth rate has not been significantly improved; however, sterile animals have become useful in oyster culture (Guo 2009) to maintain meat quality during the reproductive season and where reproduction in the wild is to be avoided (Solar 2009).

Aquaculturists can also exploit the different genetic resources found between the sexes within a species and one sex is often preferred for production. Groups of all-male tilapia produced through interspecies hybridization and sex reversal have faster growth rates and less chance of uncontrolled reproduction than do mixed-sex groups (Eknath & Hulata 2009). Single-sex populations of tilapia have diminished reproductive capacity, which reduces their chance of breeding either in grow-out or after escape.

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 (Benzie 2009). Although SPF stocks can be taken from the wild where the specific pathogen is not found, the process is greatly facilitated when reliance on wild

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AqGR is eliminated. Fear of disease transmission in other species groups has provided increased motivation to reduce the regular use of wild animals in culture. However, natural populations do have a role to play in many species.

Unlike most farmed terrestrial plants and animals, the wild relatives of farmed aquatic animals still exist in nature. In fact many farmed species are genetically very similar to wild conspecifics (Balon 1974). This further reflects the fact that genetic improvement in aquaculture is a very recent undertaking. The papers in this issue demonstrate that wild genetic resources continue to play a significant role in the production of several cultured aquatic commodities. Although one species of domesticated marine shrimp dominates production, farming of most marine shrimp accounting for over 30% of production still relies on the collection of larvae or broodstock from the wild (Benzie 2009). The establishment of the Genetic Improvement of Farmed Tilapia (GIFT) program relied on the collection of Nile tilapia from wild populations in Africa (Eknath & Hulata 2009). Oyster culture in many parts of the world relies on the natural production of spat from surrounding water bodies (Guo 2009). Wild and feral populations of common carp (Jeney & Zhu 2009) still provide genetic material for breeding centres in Asia and Europe. For emerging species in food production, recreational fisheries and the ornamental fish industry, natural populations provide nearly all of the genetic resources on which to base farming systems and breeding programs (Nguyen *et al.* 2009). In contrast, the production of farmed salmon and domesticated stocks of white-leg shrimp has almost completely eliminated the need for infusion of genes from the wild (Benzie 2009; Solar 2009).

Access to wild AqGR is often not strongly regulated or controlled and therefore returns of benefits from allowing the access of wild AqGR have not been strongly pursued. Benefits from the commercialization of AqGR are usually dependent on private business contracts and licenses.

With regard to exchange of AqGR, aquaculture is the main reason for the deliberate introduction of aquatic species to areas outside of their native range (FAO 2009a). The species groups presented in this issue are further evidence that exchange of AqGR has played a significant role in aquaculture development. For example:

- although salmon do not naturally occur in the southern hemisphere, Chile is the world's second largest producer of farmed salmon (FAO 2006; Solar 2009);
- Asia is the number one producer of African tilapia (De Silva *et al.* 2004; FAO 2006; Eknath & Hulata 2009);
- more white-leg shrimp, which are native to the Americas, are farmed in Asia than local shrimp species (FAO 2006; Benzie 2009);
- hybrids involving the North African catfish provide approximately 80% of the Thai catfish production (Na-Nakorn & Brummett 2009); and
- the Pacific oyster, introduced from Japan, is the basis for the oyster industry in North America and Europe (Guo 2009).

Part of the pattern of use and exchange of AqGR in several of the commodities studied in this issue was that genetic improvement was accomplished in areas outside of the species native range. Collections of AqGR were made from natural or farmed populations and taken to breeding centres in other areas. Atlantic salmon were genetically improved through selective breeding programs in Norway and transported to both developed and developing countries, where grow-out and local breeding programs continue (Solar 2009). Genetic improvement of farmed tilapia (GIFT) has been undertaken by international organizations and donors in the Philippines are using AqGR from commercial strains already farmed in Asia and from natural populations in Africa (Eknath & Hulata 2009). The development of domesticated strains of marine shrimp has primarily been carried out in developed countries outside of the main production areas (Benzie 2009). As breeding of most aquatic species has only recently been commercially feasible, aquaculturists have not had the millennia to farm, domesticate and genetically improve animals that terrestrial farmers have had. Therefore, most genetic improvement has relied on groups that have access to technology and funding; genetically differentiated strains are under the control of larger businesses and private agencies, and not smaller aquaculturists.

In light of concerns regarding the spread of pathogens among growing areas when AqGR are exchanged, there is a movement to reduce further exchanges and to farm and improve strains currently in production in a particular growing area (Benzie 2009; Solar 2009). This development, although potentially limiting the exchange of biological material, would increase the need to exchange technology and information, for example, in areas of breeding and genomics.

It is recognized that the movement of AqGR to new areas presents a risk to native biodiversity (Naylor *et al.* 2000) and guidelines and codes of practice have been developed by the Food and Agriculture Organization of the United Nations (FAO 1996, 2009b) and professional fishery societies (ICES 2004) to reduce the risk of adverse impacts from species introductions. The exchange of AqGR has primarily been regulated through business contracts and the concern of national governments for the environmental impacts of pathogens and invasive species (Benzie 2009; Solar 2009).

Clearly, aquaculture under the current system is developing well in many parts of the world; the value of aquaculture products (excluding aquatic plants) in 2007 was estimated to be US$87.0 billion, with developing countries providing over 80% of this production (FAO 2009b). There is an expectation that aquaculture will continue to grow, more species will be farmed and that exchange of AqGR may increase.

Aside from a few instances, the aquaculture sector has not been overly concerned with ABS issues. None of the background papers presented in this issue cited concerns over stakeholders feeling cheated over other groups accessing AqGR and benefiting from its development. However, ABS issues are starting to be raised. One example is the reintroduction of genetically improved farmed tilapia (GIFT) to Africa (Eknath & Hulata 2009). Although genetic improvement of Nile tilapia in the Philippines depended on collections of genes from natural African populations, the developers of the GIFT program adopted a policy that GIFT fish would not be used in Africa because it represented an alien genotype that could disrupt the natural gene pool of Nile tilapia. Therefore, to protect the natural genetic diversity that made establishment of the GIFT possible, the trustees of the program established a policy that Africa should receive developmental and technical assistance, but that 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 have established environmental policies and regulations prohibiting the introduction of GIFT (Greer & Harvey 2004). These policies were established when genetic resources were still viewed as common property (i.e. before the Convention on Biological Diversity) 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 has changed to permit the importation of GIFT back into Africa where consistent with national policies and legislation (WorldFish Center, unpubl. data, 2009). Another example comes from Norway. 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, and Norway is now considering legislation to govern access and benefit sharing with respect to these resources (Olesen *et al.* 2007). The Norwegian legislation seeks a way 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 foreign countries that currently grow and reproduce Norwegian salmon is unclear, but it may lead to reduced exchange and/or higher costs of improved AqGR.

One of the reasons that ABS issues may not be as prominent in the aquaculture sector as they are in agriculture is that the level and depth of traditional knowledge associated with AqGR is much less in aquaculture compared with agriculture. Again this reflects the recent emergence of farmed aquatic species, except for the ancient domestication of the common carp. In general, traditional knowledge about AqGR concerns natural history and ecosystem information that, although highly relevant to culture performance, has to date been little used in aquaculture and genetic improvement. Thus, genetic improvement and dissemination of its fruits have generally happened at commercial farms or breeding centres with access to technology and funding (Greer & Harvey 2004; Benzie 2009).

A main motivation for ABS regimes has been to ensure that those possessing the traditional knowledge and improved breeds can benefit from further commercialization of the resource by others. It was envisioned that traditional knowledge was held in developing countries by local farmers and that it was being commercialized and used by developed countries (Secretariat of the Convention on Biological Diversity 2002). In the aquatic sector the situation is much different.

Examination of the exchange of the commodities covered in this special volume indicates that the flow of material has generally not been from developing countries to developed countries, but rather in the other direction (Fig. 2). The new ABS regime seeks to change a system that is perceived to negatively impact developing countries, 'as they contain most of the world's biological diversity but feel that, in general, they do not obtain a fair share of the benefits derived from the use of their resources. Such a system reduces the incentive for the world's biologically richer but economically poorer countries to conserve and sustainably use their resources for

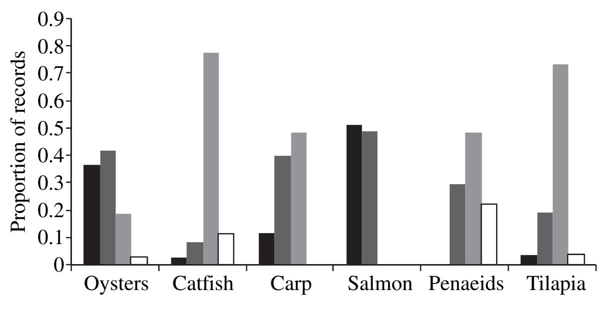

Figure 2 Introductions of selected species groups for aquaculture purposes to and from countries of different stages of development. N signifies 'north' or presumably more developed countries and S signifies 'south' or developing countries (FAO Database on Introductions of Aquatic Species; http://www.fao.org/fishery/dias).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

the ultimate benefit of everyone on Earth' (Secretariat of the Convention on Biological Diversity 2002). However, in the aquaculture sector, developing countries have benefited by allowing access to basically wild AqGR for genetic improvement by groups with access to technology and funding and by allowing the exchange of biological resources for grow-out and breeding. The diversity of farmed species and the ability to exchange that diversity among growing areas in a responsible manner has allowed the aquaculture sector to accommodate consumer demands for certain colours or shapes of fish (Jeney & Zhu 2009) and to continue to provide product and economic returns to areas where the original species became unprofitable or were diseased (Benzie 2009; Guo 2009).

The background papers in this issue illustrate that there are significant differences between the terrestrial and aquatic farming sectors; some of the major differences are highlighted below:

- 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 programs;
- 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 farming systems;
- the numbers of farmed aquatic species are increasing and farmed breeds are not being lost, except in rare cases (e.g. common carp);
- wild relatives of all aquatic farmed species still exist in nature and 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 plant 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;
- concern for compensation for providing AqGR used in other countries has not yet been widely expressed.

It will be important for future ABS regimes to recognize these differences, to include participation of aquaculturists and to recognize the need for continued development, use and exchange of AqGR and associated information to allow aquaculture to develop in a responsible manner that provides food security and economic benefits to the world.

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References

Balon EK (1974) *Domestication of the Carp, Cyprinus carpio L.* Royal Ontario Museum, Life Sciences Miscellaneous Publication, Toronto.

Benzie JAH (2009) Use and exchange of genetic resources of penaeid shrimps for food and aquaculture. *Reviews in Aquaculture* **1**: 232–250.

De Silva SS, Subasinghe RP, Bartley DM, Lowther A (2004) Tilapias as alien aquatics in Asia and the Pacific: a review. FAO Fisheries Technical Paper 453.

Eknath EA, Hulata G (2009) Use and exchange of genetic resources of Nile tilapia (*Oreochromis niloticus*). *Reviews in Aquaculture* **1**: 197–213.

FAO (Food and Agriculture Organization of the United Nations) (1996) *Precautionary Approach to Capture Fisheries and Species Introductions*. FAO Technical Guidelines for Responsible Fisheries No. 2. FAO, Rome.

FAO (Food and Agriculture Organization of the United Nations) (2006) *State of World Aquaculture*. FAO Fisheries Technical Paper 500. FAO, Rome.

FAO (Food and Agriculture Organization of the United Nations) (2009a) *DIAS. FAO Database on Introductions of Aquatic Species*. Available from URL: http://www.fao.org/fishery/dias

FAO (Food and Agriculture Organization of the United Nations) (2009b) *State of World Fisheries and Aquaculture 2008*. FAO, Rome.

Gjedrem T (2005) *Selection and Breeding in Aquaculture*. Springer, Dordrecht.

Greer D, Harvey B (2004) *Blue-genes: Sharing and Conserving the World's Aquatic Biodiversity*. Earthscan and the International Development Research Center, London.

Guo X (2009) Use and exchange of genetic resources in molluscan aquaculture. *Reviews in Aquaculture* **1**: 251–259.

ICES (International Council for the Exploration of the Sea) (2004) *ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2004*. Available from URL: http://www.ices.dk/reports/general/2004/ICESCOP2004.pdf

Jeney Z, Zhu J (2009) Use and exchange of aquatic resources relevant for food and aquaculture: common carp (*Cyprinus carpio* L.). *Reviews in Aquaculture* **1**: 163–173.

Na-Nakorn U, Brummett RE (2009) Use and exchange of aquatic genetic resources for food and aquaculture: *Clarias* catfish. *Reviews in Aquaculture* **1**: 214–223.

Naylor RL, Goldberg RJ, Primavera JH, Kautsky N, Beveridge MCM, Clay J *et al.* (2000) Effects of aquaculture on world fish supplies. *Nature* **405**: 1017–1024.

Nguyen TTT (2009) Patterns of use and exchange of genetic resources of striped catfish *Pangasianodon hypophthalmus* (Sauvage 1878). *Reviews in Aquaculture* **1**: 224–231.

Nguyen TTT, Davy FB, Rimmer MA, De Silva SS (2009) Use and exchange of genetic resources of emerging species for aquaculture and other purposes. *Reviews in Aquaculture* **1**: 260–274.

Olesen I, Rosendal GK, Tvedt W, Bryde M, Bensen HB (2007) Access to and protection of aquaculture genetic resources – Structures and strategies in Norwegian aquaculture. *Aquaculture* **272**: S47–S61.

Secretariat of the Convention on Biological Diversity (2002) *Bonn Guidelines on Access to Genetic Resources and Fair and Equitable Sharing of the Benefits Arising out of their Utilization*. Secretariat of the Convention on Biological Diversity, UNEP, Montreal.

Solar II (2009) Use and exchange of salmonid genetic resources relevant for food and aquaculture. *Reviews in Aquaculture* **1**: 174–196.