Genetic resources for aquaculture: status and trends

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1. SUMMARY

Aquaculture, the farming of aquatic plants and animals, has grown consistently since 1970, when it provided only 3.9 percent of world fish supply. In 2004, global production of farmed fish (mainly crustaceans, molluscs and finfish) was over 45 million tonnes, comprising about 32 percent of total world fish supply, while the total production of farmed seaweeds for food and extraction of chemicals, was about 13.9 million t. Aquaculture also provides increasing proportions of the world's supply of ornamental aquatic organisms. Over 90 percent of aquaculture takes place in developing countries, where it has high importance for poor people in terms of nutrition and livelihoods and where further responsible development of aquaculture, integrated with other natural resource use, has high potential for future growth. Based upon statistics submitted to FAO by its member States, about 84 percent of farmed fish production comes from Asia, with 67 percent coming from the Peoples' Republic of China. However, aquaculture is increasing in importance in all developing regions and is expected to provide about 50 percent of world food fish supply within the next 20 years.

The future of aquaculture will depend in large measure upon the effective management of the genetic resources for farmed aquatic plants (PGR) and farmed fish (FiGR), as well as those for the organisms that provide their food and ecosystem services. Fish farms are agroecosystems and aquatic genetic resources for aquaculture on farms are part of agrobiodiversity. For example, microalgae and small invertebrates are mass cultured as live feeds for production of the early life history stages ("seed") of farmed fish in hatcheries and natural feeds such as plankton are produced in fish farm waters. For some live feeds (e.g. the brine shrimp, *Artemia salina*) there is extensive information on genetic resources, but the genetic resources of most of the flora and fauna that support farmed fish production have been little explored.

The main difference between the status of most FiGR and aquatic PGR for aquaculture and all PGR and livestock ("farm animal") genetic resources (FAnGR) for agriculture is that, with few exceptions, substantial domestication and genetic improvement of farmed aquatic species lag far behind the long history of purposeful breeding and genetic gains achieved for crops and livestock. This is now changing rapidly for some widely farmed aquatic species, such as tilapias, but much of the world's production of seed for aquaculture and subsequent farm harvests remain documented mainly at the species level. Among the 80 species of livestock that are used for farming and ranching, over 6 000 different breeds have been recognized. The total number of aquatic animal species that have been farmed, experimentally or in actual production systems, is probably about 500, but the total number of farmed fish breeds has not yet been documented.

Many of the aquaculture statistics collected by governments and submitted to FAO are flawed; for example, by incomplete coverage of small-scale rural and

peri-urban aquaculture; by omission of data for some farmed aquatic species, such as freshwater macrophytes; by variable and incorrect nomenclature; and by aggregating and recording data by taxa higher than the species level. The relative importance of many genetic resources for aquaculture has still to be deduced in general terms from statistics that describe them as species, genera, families, commodity groups, and others "not elsewhere included (nei)". For example, "aquatic plants nei" have become one of the largest contributors to production statistics for farmed aquatic plants. With few exceptions (e.g. catfish and striped bass), the contributions of fish hybrids, distinct strains, and other genetically altered forms are not yet recorded in most national statistics, and therefore cannot yet be accommodated in the statistics disseminated by FAO.

Information about genetic resources for aquaculture is not yet adequately covered by major global and regional databases and online information systems, including those currently provided by FAO and those that cover in detail the biology of aquatic organisms; e.g. FishBase. Moreover, there is a widespread need for greater standardization of correct nomenclature and terminology with respect to aquatic genetic resources. Progress is, however, underway in both these areas, with operators of databases and information systems for aquatic plants, crustaceans, molluscs and finfish now striving for greater collaboration and interoperability.

Major aquaculture publications and statistics reviewed from 1972 to 2004 suggest the following approximate ranges of numbers of farmable and potentially farmable aquatic organisms identified to species: microalgae, about 5 named as species, but with 16 genera also named; freshwater macrophytes, 5-8; marine macroalgae (seaweeds), 13-24; crustaceans, 26-79; molluscs, 20-74; other invertebrates, 4-7; finfish, 122-294; amphibians and reptiles, 3-11. Further exploration and documentation of the genetic resources of such large numbers of species - as wild and captive populations, geographical races, distinct farmed strains, hybrids and other genetically altered forms - will be a large task. However, the genetic resources for farmed aquatic plants could be covered under existing arrangements for terrestrial PGR and the most important FiGR for aquaculture could be prioritized; for example, by choosing initially the top 50 to 100 species that contribute most to farmed fish production, though with flexibility to include others that have clear potential importance and/or any wild and farmed FiGR that appear most threatened with extinction.

Consumer preferences are the main driver for farmers' choices of which fish to farm. However, most of the world's aquaculture and culture-based fisheries production is based on seed produced from broodstock populations by the operators of fish hatcheries. Public and private seed producers, their breeding programmes and related research determine largely which types of seed are available for purchase by farmers, for subsequent growout to marketable size. Fish farms range in size from small-scale/backyard to large scale corporate ventures. Vertically integrated aquaculture, similar to broiler chicken production, is also expanding. Most aquaculture is undergoing intensification to boost production per unit area or volume of farm waters. This requires the development of strains, hybrids and other genetically altered forms that are tailored to intensive farming, especially with respect to commercial traits such as good feed conversion, disease resistance, fillet yield, colour, flavour, etc.

Because of the short history of domestication, breeding programmes and related research for most farmed aquatic organisms, the free-living populations of their wild and feral relatives and of other potentially farmable aquatic species have high importance as genetic resources. Many of these free-living populations, especially in freshwaters, are among the world's most seriously threatened biodiversity; for example, the wild genetic resources of farmed carps and tilapias. Moreover in aquaculture, as in agriculture, most private sector seed producers and farmers keep only the most profitable farmed species and types, leaving others under threat of extinction. The use in aquaculture production and related research of alien species and of genetically altered forms (e.g. distinct strains, hybrids, polyploids, trangenes etc., whether developed from alien and/or indigenous species) is certain to increase. This will require more effective biosafety and biosecurity procedures than have been implemented to date, particularly with respect to thorough appraisal of the impacts of escapes and releases of farmed aquatic organisms before granting approvals for introductions and transfers, as well as strictly enforced quarantine.

These trends indicate an urgent need for better management – meaning fully integrated use and conservation – of aquatic genetic resources for aquaculture: *in situ/in vivo*, as free-living, wild and feral populations; *in situ/in vivo*, as captive populations on-farm; *ex situ/in vitro*, as collections of cryopreserved sperm, embryos and other tissues/DNA; and *ex situ/in vivo* as aquarium and research populations. This will require increased investment in the management of FiGR and aquatic PGR, commensurate with their high and growing contributions to world food security, Keeping representative, free-living wild populations of farmed fish species undisturbed in their natural habitats and off-limits to aquaculture and to contact with farmed fish, has operational and opportunity costs. Therefore, unless there is equitable sharing of costs and benefits among the stewards and potential users of such aquatic genetic resources for aquaculture, the conservation element in their management will not be achieved. Establishing and maintaining *ex situ, in vivo* and/or *in vitro,* fish gene banks is also expensive and will require public and private sector investment and partnerships. Attempts by the private sector to acquire intellectual property rights on genetically altered fish and related biotechnological processes in aquaculture have so far been limited, compared to the situation in plant breeding. It is unlikely that attempts to enforce proprietary rights on genetically altered fish will prosper in the near future. Rather, as public and private fish breeding programmes develop, returns to fish breeders will likely come from purchased access to pedigreed fish populations and eventually to pedigree individuals, as for livestock and pet animals. However, private sector research, especially for the development of biotechnological products and processes, is bound to increase in aquaculture, following the trends in agriculture.

The following strategic directions are suggested for improving the management of genetic sources for aquaculture: increased investment; management (i.e. fully integrated use and conservation) as part of agrobiodiversity; improved information systems; conservation in changing ecosystems; reconciliation of aquaculture with nature conservation; progressive linking of the management of aquatic PGR and FiGR with that for terrestrial PGR and FAnGR; and exploration of the application of an interactive governance approach, with assessments of the governability of aquatic genetic resources.

2. INTRODUCTION

Aquaculture is the farming of aquatic plants and animals. It comprises the mass production, usually in hatcheries, of "seed" (eggs, larvae, postlarvae, fry, fingerlings, juveniles etc.) of farmed aquatic organisms, and the subsequent growout of that seed to marketable size in aquatic farms or its release for culture-based fisheries (CBF) (e.g. see Bartley and Leber, 2004; Caddy and Defeo, 2004). Hatchery operations for CBF are generally considered part of aquaculture. The FAO Code of Conduct for Responsible Fisheries (FAO, 1995) and its guidelines for aquaculture development (FAO, 1997) refer throughout to "*aquaculture, including culture-based fisheries*". Seed is produced mainly from captive breeding populations. However, for the minority of farmed aquatic species where mass production of seed in captivity is not yet technically possible, or where its collection from wild populations still makes economic sense, wild seed or young adults are obtained from capture fisheries and then grown to marketable size in captivity. This can be termed capture-based aquaculture (e.g. Ottolenghi *et al.,* 2004).

This review is concerned mainly with the genetic resources of fish, meaning finfish and aquatic invertebrates (principally crustaceans and molluscs) that are farmed or potentially farmable. The genetic resources for CBF, as well as their genetic impacts on wild populations, are not considered here. Most farmed aquatic plants and animals are used for human consumption as food but some are farmed for other purposes; e.g. for extraction of industrial chemicals (seaweeds), as ornamental species (aquatic plants, invertebrates, finfish, amphibians and reptiles), for sport fisheries (finfish) and for cosmetic, jewelry, and medicinal products (molluscs, seahorses etc.). It is implicit in this review that policy and other provisions made for the genetic resources of aquatic organisms farmed as human food should apply also to those of aquatic organisms that are farmed for other purposes. Genetic resources for farmed aquatic plants are covered briefly here, emphasizing macroalgae (seaweeds) farmed for human food or for extraction of chemicals. All genetic resources for farmed aquatic plants are called PGR.

By convention, all fish genetic resources for aquaculture and capture fisheries are now termed FiGR. FAO aquaculture statistics include farmed macroalgae within a general definition of "fish", but their genetic resources are PGR, not FiGR. Farmed aquatic amphibians and reptiles also figure in FAO and some other farmed fish statistics, but can be considered as livestock ("farm animal") genetic resources (FAnGR), thereby restricting the use of the term FiGR for farmed aquatic vertebrates to finfish alone. Similarly, the farming of aquatic birds and mammals is not considered part of aquaculture, and their genetic resources are regarded as FAnGR, not FiGR. Farmed amphibians and aquatic reptiles are mentioned here only insofar as they are included in FAO aquaculture statistics and major texts.

This review builds upon recent publications that address conservation and use of aquatic genetic resources (e.g. Pullin *et al.,* 1999; Pullin, 2000, 2006b; Science Council Secretariat, 2005). The importance of aquaculture, its rapid growth and dynamic nature are summarized, with overviews of the main categories of genetic resources for aquaculture; i.e., for feeds and ecosystem services, aquatic plants and fish. Discussions follow on factors that affect the status of and trends in genetic resources for aquaculture: choosing what to farm; information and nomenclature; threats; management, defined as fully integrated use and conservation; and the sharing benefits and costs, including ownership and use issues. No order of priority is implied here. The review concludes by identifying some strategic directions for improving the management (i.e., the fully integrated use and conservation) of genetic resources for aquaculture.

3. THE GROWING IMPORTANCE OF AQUACULTURE

FAO is the source of all aquaculture statistics quoted here, unless otherwise stated. FAO began to publish statistics in 1950 but, up to 1984, aquaculture statistics were combined with those for fish catches. Despite their subsequent separate status and increasing importance, world aquaculture statistics are still beset with uncertainties. There is a widespread need to improve collection of data from small-scale, rural aquatic farms, especially in developing countries. The world's small-scale rural and peri-urban aquaculture production, as well as its value and importance in household food security and provision of incomes and employment are probably substantially under-recorded in many national statistics. Moreover the real, as opposed to perceived, contributions of many CBF to world fish supply are poorly known and will remain so unless data for their seed production and harvests are adequately disaggregated from those for growout on farms and capture of wild fish. Uncertainties concerning the current contributions and future potential of CBF have been mentioned by many authors (e.g. Lorenzen *et al.,* 2001; Leber *et al.,* 2004). There is also a need to analyse trends in aquaculture both with and without inclusion of the statistics reported by the Peoples' Republic of China (PRC) (e.g. New, 2003).

Despite these uncertainties, the present contributions of aquaculture to world food security and its future potentials are well recognized. Aquaculture has large potential for further growth, not only in the countries where it is well-established but also in many of those where it is relatively new, including sub-Saharan Africa and Latin America. Governments in all developing regions have framed and begun to implement policies that place reliance on expansion and intensification of aquaculture for sustaining and increasing their fish supply (e.g. see Brugère and Ridler, 2004).

In 2002, the status and future prospects of aquaculture were described as follows in a background paper for the first meeting of the FAO Sub-Committee on Aquaculture (FAO, 2002):

"Aquaculture is an important domestic provider of much needed, high quality, animal protein, generally at prices affordable to the poorer segments of society. It is also a valuable provider of employment, cash income, and foreign exchange, with developing countries contributing over 90 percent of the total global production. When integrated carefully, aquaculture also provides low-risk entry points for rural development and has diverse applications in both inland and coastal areas."

Annual rates of increase for aquaculture production and value have varied greatly with species and farming systems but, since the 1970s, almost all have been higher than those for other food production sectors and remain so. For example, shrimp farming in the late 1970s grew at 24 percent per year and FAO (2002) described its 6 percent average annual growth rate in the 1990s as "modest". Farmed fish currently provide about 32 percent of world food fish supply, compared to about 3.9 percent in 1970 and their contributions are widely expected to grow to about 50 percent, probably within the next 20 years. According to McHugh (2003), most of the world's production or macroalgae for human food and for extraction of chemicals (hydrocolloids) is derived from aquaculture. For 2004, FAO statistics indicate total world production of 13.9 million tonnes of farmed aquatic plants, worth about $6.8 billion. Aquaculture is also an increasingly important source of supply for ornamental freshwater and marine tropical fish, in developed and developing countries. Information on ornamental plants and animals is widely available through global databases (e.g. for marine fish and invertebrates, see www.unep-wcmc.org).

A nutrition transition, from diverse, traditional fish-, fruit- and vegetable-rich diets to fat-, sugar- and alcohol-rich diets, is underway in the developing world and is causing rapid growth of diet-related, chronic diseases (ischemic heart disease, diabetes, obesity, hypertension, stroke, and certain cancers), with high consequential costs. In 1995, these diseases accounted for 41.6 percent of all deaths and 22.5 percent of all hospital expenses in the PRC, equivalent in total to 2.1 percent of gross domestic product (GDP), while for Sri Lanka the corresponding figures were 18.3 percent, 16.7 percent and 0.3 percent of GDP (Popkin *et al.,* 2001). Gillespie and Haddad (2001) reviewed the "double burden" of malnutrition: undernutrition and overnutrition from overconsumption of unhealthy foods. Farmed fish will be increasingly important contributors in efforts to solve these problems, especially as they can provide substantial nutritional and livelihood benefits to the poor (e.g. ADB 2005a; FAO/NACA-STREAM 2005). For many developing countries, aquaculture is the main hope for sustaining and increasing contributions of affordable fish and fish products to healthy diets. Fish provide their consumers with animal protein, health promoting lipids and essential vitamins and minerals and are particularly important in human nutrition as sources of the omega-3 fatty acids necessary for brain development in the human foetus and its functioning throughout life (e.g. Elvevoll and James, 2000; Anon., 2006).

Aquaculture is often categorized according to the feeds available to farmed fish. In extensive aquaculture, fish depend entirely on the natural productivity of farm waters,

TABLE 1
Production (tonnes (t) and value (US$, thousands) in 2004 of farmed fish (mainly crustaceans, finfish and molluscs) for the top ten producer countries and the rest of the world.

Producer countries	Production (t)	Value ($ thousands)
1. People's Republic of China, excluding the Hong Kong SAR	30 614 998	30 869 609
2. India	2 472 335	2 936 479
3. Viet Nam	1 198 617	2 443 589
4. Thailand	1 172 866	1 586 626
5. Indonesia	1 058 042	2 130 004
6. Bangladesh	914 752	1 363 180
7. Japan	776 421	3 205 093
8. Chile	674 979	2 801 037
9. Norway	637 993	1 688 202
10. USA	606 549	907 004
Subtotal	**40127 552**	**49 930823**
Rest of the world	5 353 375	13 562 462
TOTAL	**45480 927**	**63 493 285**

Source: FAO Statistics

supplying natural feeds: plankton, detritus, vegetation etc. In semi-intensive aquaculture, relatively cheap supplementary feeds are given, and the production of natural food in farm waters is sometimes artificially increased by fertilization. In intensive aquaculture, farmed fish are entirely dependent upon provision of nutritionally complete feeds, which typically account for about 65 percent of the total variable costs of production. Intensification, through maximizing use of pond fertilizers and supplemental feeds to intensive feedlot systems, is now a major trend for most forms of aquaculture. This boosts production per unit area or volume of farm waters, but makes large ecological footprints beyond farming areas. The main exceptions to this are seaweed farming and most farming of bivalve molluscs, which remain largely extensive aquaculture operations, involving minimal husbandry from seed to harvest.

Table 1 summarizes the most recent aquaculture production and value statistics (2004), by the top 10 leading countries and the rest of the world, for fish farmed for human food. From these data, Asian countries accounted for 84 percent of world aquaculture production in 2004, with the PRC alone accounting for 67 percent. Note the higher values accorded to aquaculture produce in the more developed countries.

4. GENETIC RESOURCES FOR AQUACULTURE

4.1 Feeds and ecosystem services

All sources of human food production, including aquaculture, are interconnected as a global food web. The genetic resources for the cereal crops and other plants that provide ingredients for the feeds given to farmed fish are genetic resources for aquaculture. Similarly, the genetic resources for the low value/trash fish (LV/TF) and industrial fisheries that provide fish, fishmeal and fish oils for feeding farmed fish and livestock are genetic resources for both aquaculture and livestock production. However, Tacon *et al*., (2006), citing FAO (2005), pointed out that only 18.2 percent of global fishmeal production and 45 percent of fish oil production is currently attributable to named species. This means that many of the FiGR for fishmeal are fish oil production are undocumented, even at species level. From a world food security perspective, it is important to note that aquaculture production which remains based upon substantial use of wild caught fish, fishmeal and fish oil, cannot be claimed as a net gain in fish supply or as a net contribution to filling the gap in fish supply caused by declining capture fisheries. Tacon *et al.,* (2006) estimated that in 2003 the "aquaculture sector" consumed as feeds the equivalent of 20 to 25 million tonnes captured fish, as live weight equivalents, in order to produce 30 million tonnes of farmed finfish and crustaceans. They identified the following groups of farmed fish as net consumers or producers of fish: net consumers – river eels, marine fish and shrimps, salmon and trout; net producers – carp, catfish, freshwater crustaceans, milkfish and tilapia.

Production of fish seed in aquaculture and for CBF often involves protein-, essential lipid- and micronutrient-rich starter fish feeds; supplied in fine particulate form or as live food organisms, cultured or collected specifically for this purpose; e.g. bacteria, microalgae, rotifers, crustaceans and molluscan larvae. The genetic resources for organisms that are used to produce these feeds and for live food organisms used in aquaculture are also genetic resources for aquaculture. The status and diversity of some of the latter are well-documented; for example, there are interlinked collections and information sources for cultured bacteria and microalgae and a reference centre for the brine shrimp *Artemia salina* and the rotifer *Brachionus plicatilis* (www.aquaculture.ugent.be).

Many other microbial, plant and animal species provide farmed fish with food and feed ingredients and with a wide range of ecosystem products and services, including oxygen, shelter, spawning substrates and waste processing. Their genetic resources are essential for the future of aquaculture, being broadly analogous to the genetic resources for organisms that contribute organic fertilizers for the production of crops and fodders for livestock. Inedeed, all species that provide feeds and ecosystem services to aquaculture are part of agrobiodiversity when found on-farm; i.e., in agroecosystems. These supportive genetic resources for aquaculture merit much wider recognition and documentation, and above all more effective management, than they have received to date.

4.2 Farmed aquatic plants

Farmed aquatic plants comprise green microalgae (e.g. Chlorella); blue-green algae, more properly termed cyanobacteria (e.g. Spirulina); macroalgae (brown, green and red seaweeds); and freshwater macrophytes (e.g. floating species, such as azolla and duckweeds, and emergent species such as lotus, water chestnut and water spinach). Table 2 gives numbers of farmed aquatic plants identified to species in some major aquaculture publications.

Farmed microalgae are not well covered in most aquaculture literature, except as live feeds for fish hatchery operations. FAO statistics give production of farmed Spirulina in 2004 as 41 750 tonnes. *Chlorella vulgaris* is listed, but with zero production recorded. Stickney (2000) mentioned 16 farmed microalgal genera.

TABLE 2

Numbers of farmed aquatic plants that are named as species in some major aquaculture publications, including species under experimentation and/or having potential for aquaculture as well as those used in actual production systems

Farmed aquatic plants	Numbers of species			
	A	B	C	D
Microalgae	5	2	-	1
Freshwater macrophytes	8	5	5	-
Marine macroalgae (seaweeds)	15	24	-	13
TOTAL	28	31	5	14

Source A: Bardach *et al.* (1972); B: Pillay (1990); C: Stickney (2000); D: FAO aquaculture statistics (2004)

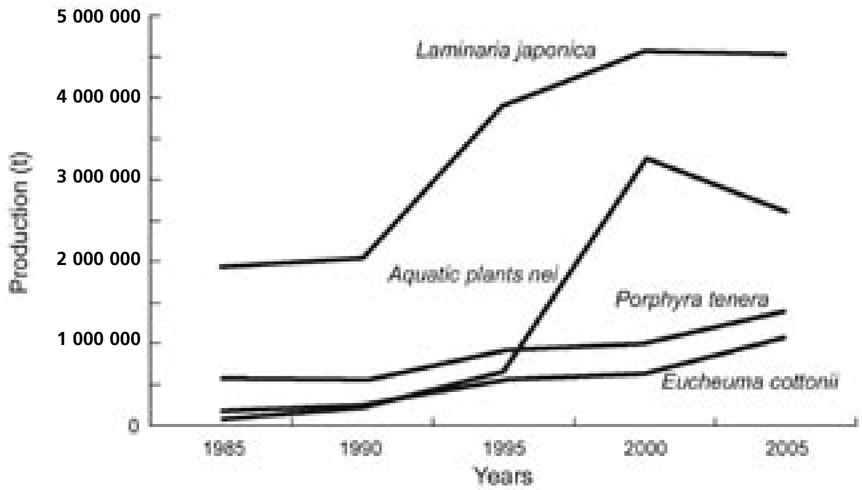
Despite their high importance as human food, as fodders and fertilizers in agriculture and as components of waste treatment systems (e.g. Edwards, 1980; Van Hove, 1989; Kanungo *et al.,* 2001), farmed freshwater macrophytes are not well covered in mainstream aquaculture literature and FAO aquaculture statistics. Some freshwater macrophytes – for example, water spinach (*Ipomea aquatica*) are major crops, but information on their production and their genetic resources is not easily obtained, either from agriculture or aquaculture sources. Conversely, the wetland and deepwater rice, which are aquatic macrophytes, are well covered by mainstream crop genetics literature. Most of the available information on other freshwater macrophytes concerns control of nuisance species; for examples, see the Journal of Aquatic Plant Management; http://www.apms.org/japm/japmindex.htm. However, a new "forum" about peri-urban farming of freshwater macrophytes and fish is being established, based upon examples in Southeast Asian cities (contact: W. Leschen; wl2@stir.ac.uk).

FAO statistics for farmed aquatic plants focus on marine macroalgae (seaweeds) and are included with farmed fish statistics. They name only eight macroalgal species and group others together within seven genera and/or as higher taxa. The major contributors to world farmed seaweed production that are identified to species are *Laminaria japonica*, *Porphyra tenera*, and *Eucheuma cottonii*. Large contributions are said to come from "aquatic plants nei" (i.e. not elsewhere included), which are assumed to be macroalgae. Production of these aquatic plants nei has tended to increase, mainly because of the larger quantities reported from the PRC since 1998 (1 946 980 tonnes) as compared to 1997 (461 675 tonnes). Prior to 1998, production of farmed seaweeds in the PRC was reported on a live (wet) wet basis, whereas from 1998 it was recorded first as dry weight and then reported after applying conversion factors (A. Lowther, personal communication). Figure 1 shows the trends in production of the four major farmed species, plus aquatic plants nei, from 1985 to 2004.

McHugh (2003) forecast limited scope for expansion of seaweed farming as follows: to supply agar, limited; to supply alginates (typically from *Laminaria japonica*), about 2-3 percent per year; to supply carrageenan, about 5 percent per year; and as human food, highly variable prospects, dependent upon promotional efforts. However, seaweed farming undoubtedly has potential to improve the lives of some poor and marginalized

FIGURE 1

Production (tonnes; t) of major species of farmed macroalgae and others "not elsewhere included (nei)" from 1985 to 2003



Source: FAO statistics

coastal communities, especially in the tropics. For example, in the Philippines Autonomous Region in Muslim Mindanao, some poor coastal communities in the farm seaweed as contract growers, for exporters of seaweed products. In 2004, this region produced 472 514 tonnes of farmed seaweed: over 50 percent of the Philippine national total of that used for exportable seaweed products (Unson, 2006). Against the many actual and potential benefits of seaweed farming, there is serious cause for concern when alien macroalgal species are introduced for aquaculture to new coastal locations without through prior appraisal of their possible ecological impacts.

More detailed coverage of production and value data for farmed aquatic plants, with authoritative and correct names at species level, is an essential prerequisite for monitoring the status of and trends in their genetic resources. This merits high priority, not only for the major commercial species groups but also for those that are of high importance as contributors to the food and livelihood opportunities of poor communities; e.g. *Caulerpa* spp. in tropical Asia. The database www.algaebase.org is a good source of information on correct taxonomy and nomenclature of algae and could be supplemented to give information on the genetic resources of farmed algae. At present, however, most information about these PGR is scattered and is to be found mainly in the major phycological journals and occasionally in those that cover aquaculture in general (e.g. Cheney 1999). It could be collected and made accessible through existing arrangements for terrestrial PGR, given additional investments.

4.3 FARMED FISH

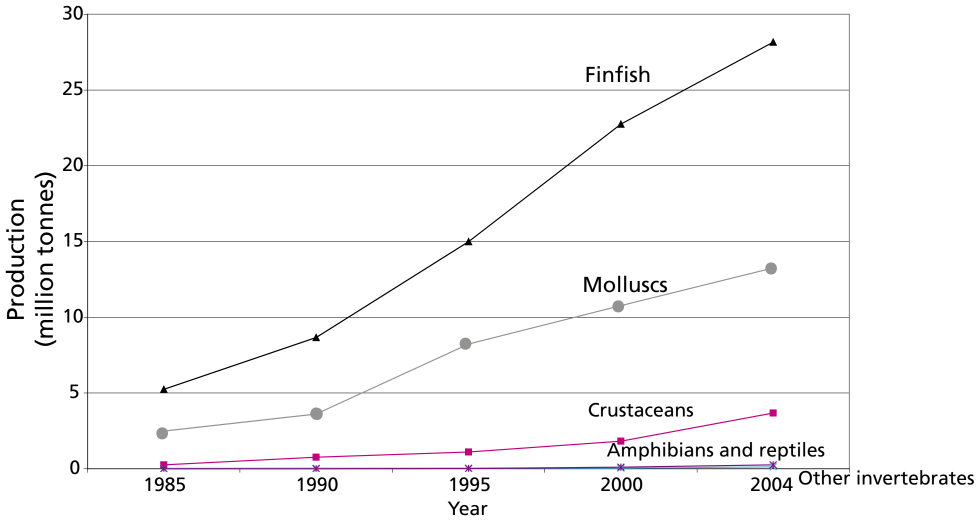
FiGR for aquaculture can categorized in a wide variety of ways: by taxonomy and genetic terminology (e.g. allele, selected strain, hybrid, artificial polyploid, transgene, species, genus, family, order, commodity group etc.); by location (area of production; natural and introduced geographic ranges; by free-living and/or farm environments, including migratory habits (brackishwater/diadromous; freshwater; marine) and production systems (cages, pens, ponds, raceways, recirculating systems, tanks, etc.); by relative current worth (production tonnages, monetary values, nutritional importance, poverty alleviation through livelihood provision and diversification, sociocultural value; sport and recreational value etc. However, the main basis for categorization of FiGR for aquaculture is their actual and potential use, as indicated by aquaculture statistics and research findings. Table 3 gives numbers of farmed aquatic animals identified to species in some major aquaculture publications.

TABLE 3
Approximate numbers of farmed aquatic animals that are named as species in some major aquaculture publications, including those having potential for farming

Farmed aquatic animals	Numbers of species				
	A	B	C	D	E
Invertebrates					
Crustaceans	79	38	45	26	38
Molluscs	61	43	74	20	64
Others (mainly echinoderms)	-	-	-	7	4
Subtotal	**140**	**81**	**119**	**53**	**106**
Vertebrates					
Finfish	294	130	201	122	212
Amphibians and reptiles	6	-	11	6	3
Subtotal	**300**	**130**	**212**	**128**	**215**
TOTAL	**440**	**211**	**331**	**181**	**321**

Sources A: Bardach *et al.* (1972); B: Pillay (1990); C: Nash (1993); Nash and Novotny (1995); D: Stickney (2000); E: FAO aquaculture statistics (2004)

FIGURE 2
Production (tonnes; t) of farmed fish (crustaceans, finfish and molluscs) from 1985 to 2003



Source: FAO statistics

FAO aquaculture statistics retain data entry lines for species and higher taxa for which zero production and value are recorded. For some, production has been zero for decades. This means that FAO's aquaculture statistics are records of all historical use of these species and higher taxa, not just records of recent and current farming. Figure 2 shows the production of farmed fish by major groups (crustaceans, finfish and molluscs) from 1985-2004, with production of other farmed aquatic invertebrates and of farmed aquatic amphibians and reptiles seen as very small by comparison.

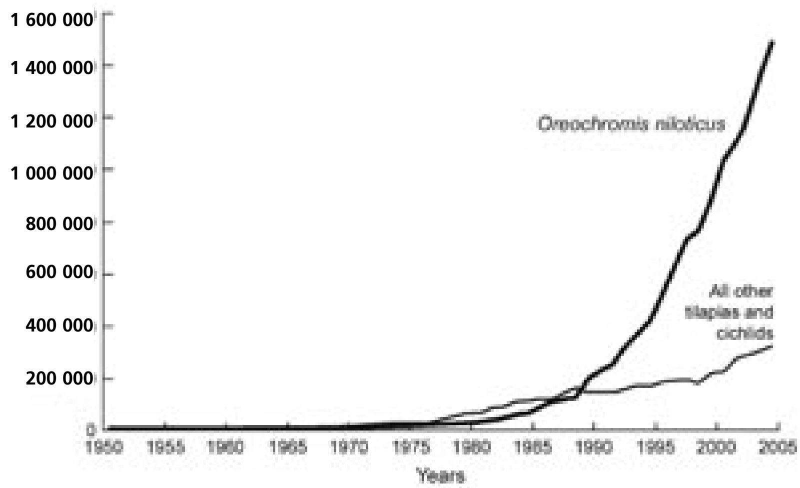
As Bartley *et al*., (2001) have shown, interspecific fish hybrids are used in aquaculture, but their contributions to production go largely unrecognized and, with very few exceptions (e.g. hybrid catfish [*Clarias gariepinus* x *Clarias macrocephalus*] and hybrid striped bass [*Morone chrysops* x *Morone saxatilis*]), are not yet captured adequately in national or FAO statistics. The data from member countries, upon which FAO statistics are based, is given only at species level or at higher taxa comprising unspecified numbers of species; for example, genus + "spp." and "not elsewhere included". There is no information concerning any taxon below species level.

FAO statistics can be analysed in various ways to attempt to prioritize farmed aquatic species. Contributions not only to aquaculture production and value but also to availability of produce that is affordable by poor consumers would probably be the most equitable and best broad measure. Such prioritization would, however, be a lengthy exercise and is not attempted here. A good general idea of the approximate numbers of important farmed fish can be gained from recent analyses. For example, New (2003) lists the following numbers of clearly important species: 8 crustaceans; 10 molluscs; and 26 finfish (13 freshwater, 7 diadromous and 6 marine). This gives a total of 44 most important species, but more flexibility and inclusiveness are needed to prioritize FiGR for aquaculture because some species are of special importance to only one or a few countries.

The relative national and international importance of a farmed aquatic species can change rapidly; for example, farmed Nile tilapia (*Oreochromis niloticus*) production has shown extraordinarily rapid growth in recent years (Figure 3), though a substantial proportion of what is currently recorded as production of farmed Nile tilapia is

FIGURE 3

Production (tonnes; t) of the world's main farmed tilapia species *(Oreochromis niloticus)* and of all other farmed tilapias and other cichlids from 1950 to 2003



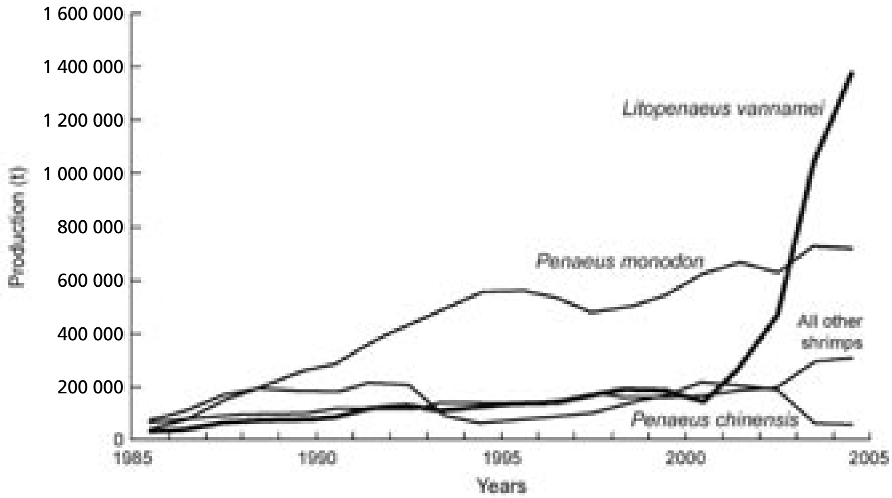
Source: FAO statistics

probably of tilapia hybrids having this species as one of the parents. The Pacific white shrimp (*Litopenaeus vannamei*) has rapidly become the main species of farmed penaeid shrimp. The data shown in Figure 4 are probably underestimates of its increasing contributions, because some countries reporting to FAO take time to adjust their reporting by species as the proportions of farmed species change. *L. vannamei* probably now accounts for over 80 percent of farmed penaeid shrimp production in Asia.

The world's FAnGR for livestock farming and ranching comprise about 80 species, of which 14 contribute most to world production and within which over 6 000 breeds have been recognized, whereas the world's FiGR for aquaculture probably comprise about 500 species that have recorded as having been farmed to some extent (including experimentally) at some time (Pullin, 2006b; Science Council Secretariat, 2005). FishBase (www.fishbase.org) has listed 344 species of farmed finfish. However, data currently available at species level in aquaculture statistics and aquaculture research literature suggest to this author that substantial coverage of FiGR for aquaculture could be achieved by prioritizing 50 to 100 species of farmed and potentially farmable fish, taking into consideration their international and national importance as well as their status, especially where they are threatened (see 7. below).

All major livestock species are considered fully domesticated. Their few remaining wild relatives are of low importance for future breeding programmes, and there are few new potential candidate species for farming. Most farmed fish species are not yet fully domesticated. Their wild relatives are of high importance for breeding programmes and related research, and there are many (possibly hundreds) of new potential candidate species for aquaculture. Balon (2004) argued that only the common carp (*Cyprinus carpio*) as a farmed food fish and as koi ornamental carp, the goldfish (*Carassius auratus*) and a few other ornamental species can be called true domesticates, with other farmed fish (including Chinese and Indian carp, catfish, salmon, sturgeon and trout species) qualifying only as "exploited captives", apart from their few colour variants, such as albino strains, that can be termed "domesticated". There is good evidence to support this view. For example, the diversity and stability of goldfish (*Carassius auratus*) breeds are comparable to those for dog breeds (e.g. Zhen, 1988), but most

FIGURE 4
Production (tonnes) of three major species of farmed penaeid shrimps and of all other farmed shrimp species from 1985 to 2003



Source: FAO statistics.

farmed fish strains and hybrids look alike and the consumer of farmed fish and farmed fish products does not yet have breed-specific choices, comparable to those available for many livestock products. At present, the world's farmed fish are represented by relatively few well-documented, distinct and stable breeds.

Prior to the big expansion of application of genetics in aquaculture that began in the late 1980s, development of and documentation about distinct and stable breeds and hybrids of farmed fish were poor. Even by the 1990s, fish breeds and hybrids had not been developed for particular farm environments and farming methods and for most farmed aquatic species, particularly in the developing countries, well-documented FiGR of known provenance were simply not available. This meant that the products of any well-reputed genetic improvement research were almost certain to enjoy high demand for use in a wide range of farming systems. GIFT and GIFT-derived Nile tilapia are a good example. Having been bred from initial research trials in a wide range of farm environments from ricefields to ponds and cages (Eknath *et al.,* 1993), GIFT and GIFT-derived Nile tilapia have been farmed in most tilapia farming systems and, in view of their broad genetic base, have become the main basis for national tilapia breeding programs in several countries (ADB, 2005b).

Parallel to the intensification of aquaculture, there is an ongoing quest to push many farmed aquatic species towards omnivory and acceptance of least-cost formulated feeds, irrespective of their natural feeding habits (Pullin, 2006a). Many farmed fish, especially marine species, are naturally carnivorous but are being constrained to accept feeds containing as much plant and microbial protein as is biologically possible, as well as a wide range of rendered livestock and other waste products. Conversely, many widely farmed and naturally herbivorous and omnivorous fish species (such as grass carp and Nile tilapia) are being farmed more and more intensively, using feeds containing fishmeal, rendered livestock products etc. In general, these trends require the development of fish strains, hybrids and other genetically altered forms that perform well in intensive farming systems, that show good feed conversion on low cost feeds, that yield attractive and well-flavoured products, and that enjoy high survival and growth performance in adverse environments; for example, cold- and saline-tolerant tilapias. Breeding programmes and related research that compare these and other commercial traits among different farmed strains, hybrids and other genetically altered forms are therefore increasing (e.g. Rutten *et al.,* 2004a, 2004b) and will draw upon FiGR from farmed, wild and feral populations, including those established in adverse environments. Costa-Pierce (2003) recognized the importance of feral tilapia populations and recommended establishment of a registry using genetic markers. Over the past 30 years, fish breeding programmes and related research have been undertaken largely by public institutions and organizations, but will be increasingly pursued by public-private partnerships or by the private sector alone.

5. CHOOSING WHAT TO FARM

Genetic improvement of farmed fish lags far behind genetic improvement of crops and livestock but is taking similar approaches. Crop breeding and related research are increasingly driven by market assessments of demand for certain types of seed, with the development and importance of different genetic resources (varieties, hybrids, etc.) determined mostly by demand-led technical change, rather than supply-led proposals from scientists (P. Pardey, personal communication). The same trends are likely to develop in fish breeding.

Fish consumers determine the demand for different types of farmed fish at any given time, while aquaculture science works to develop and to introduce new options. Most fish consumers are, however, unaware of the existence and importance of FiGR. They usually buy, or receive (for example, in disaster relief operations) aquatic produce that they know only by common names. Their categorization and choices of produce usually approximate to species level, though they often know the names of the places of production of farmed fish (e.g. Scottish salmon in the United Kingdom; Batangas Province tilapia in the Philippines) and seek produce from a named location, based on their previous experience of buying it or on perceptions about its quality. The naming of places of production in fish markets, as in fish restaurant menus, is often a marketing ploy and does not usually provide reliable information about the genetic identity of produce. For example, some of the salmon farmed in Scotland and other countries were bred in Norway, and many farmed salmon look alike irrespective of origin and breeding history. In developing countries, there is rarely any independent certification that fish in the market place bearing the name of an area or farm of origin all came from there.

In many countries, though primarily at present in the developed world, consumers' choices of farmed fish are being made increasingly on ethical grounds. Ethics and responsibility in aquaculture have been reviewed by Kaiser (2002). For fish consumers, the main factors are whether farmed fish are treated humanely and whether they are produced in environment- and biodiversity-friendly farming systems; considering not only the obvious impacts of effluents from fish farms, abuse of antibiotics, etc., but also the choice of fish with feeding requirements – preferably herbivorous/omnivorous – that will not exacerbate pressures on capture fisheries that are already overexploited. Public perceptions of genetic modification of food species are also a major factor in ethically-based choices of what to eat, irrespective of considerations of biosafety and food safety. All such ethical considerations are being applied to farmed fish, particularly as organically farmed fish are becoming new entrants to organic agriculture (www.ifoam.org). Fish welfare issues, including those of farmed fish have been reviewed by Huntingford *et al*. (2006).

In most aquaculture, as in most agriculture, seed production and growout are separate enterprises, in different hands. Also in aquaculture, as throughout agriculture, seed producers' and farmers' choices of which aquatic organisms to farm are determined by market demand, profitability, and technical feasibility. Assessments of all of these imply risk assessment and management, and these in turn require information as well as adequate knowledge and skills. Seed producers and farmers base their choices of fish upon their own experience and/or external advice concerning a wide range of commercial traits: e.g. for seed producers, fecundity of and egg quality from broodstock, and survival, growth rate and disease-resistance of seed; for farmers, survival, growth rate, feed conversion, disease resistance, dressing weight, color, flavour etc. Many farmers, especially small-scale farmers in developing countries, have to make choices about what to farm while lacking adequate science-based information and independent advice on the genetic diversity that is available and on the performance of different species, hybrids and strains. The links in the "chain of choice" concerning what to farm are at their strongest in modern, vertically integrated aquaculture and agriculture, where research, breeding, seed production, contract growing, processing and marketing are all or mostly undertaken within the same organization – usually a large food company which also manufactures feeds and supplies technical support services. Some forms of aquaculture, such as intensive farming of Nile tilapia, already resemble vertically integrated poultry farming though, like chickens, tilapia can also be farmed in a wide range of systems from free range through backyard feedlot to small, medium and large scale commercial farms (e.g. see Young and Muir, 2002).

Although choices about which fish are farmed are primarily consumer-driven, many other actors, including researchers, breeders, and fish processors, also influence these choices. Decision-making along this chain is a research area that has been little explored, but it is probable that some of its links are weak or even disconnected. Most fish consumers, and indeed fish farmers, feel that they know what need, while researchers, breeders and seed producers tend to promote their new ideas and products, often with strong political and commercial backing. Sometimes this results in large benefits to farmers and consumers, sometimes not. A good positive example was the development of new technology for the farming of genetically improved farmed tilapia (GIFT) (ADB, 2005b). However, interactions among aquaculture scientists, seed producers, farmers and fish consumers are often weak. Globalization is increasing the remoteness of some fish farmers from their markets. For others who remain closer to their markets, consumer demand and profit margins clearly dictate the choice of what to farm. An important recent example can be seen in the switch made by carp farmers in Andra Pradesh, India, from following long-established, scientist-derived polyculture formulae, that required stocking six (three indigenous and three alien) carp species in all ponds, to a much simpler system of stocking just two indigenous carp species, resulting in greater yields and profits (Nandeesha, 2001). This worked because of the high price of one of these species (*Catla catla*) and the opportunistic feeding behaviour of the other (*Labeo rohita*). The theoretical basis of multispecies polyculture – different species occupying separate feeding niches (benthos, detritus, phytoplankton, zooplankton, etc.) – tends to break down as aquaculture is intensified.

The other main actors whose activities influence current and future choices of what to farm, as well as where to farm it, are the conservationists at all levels (international, national and local/community) who recognize the need to conserve not only the genetic resources of farmed aquatic organisms, but also those of their wild relatives, of farmed types for which production has been discontinued, and of potential new candidate species for aquaculture. The overall goal here is to maximize options for future availability and use of FiGR and aquatic PGR. In agriculture, conservation of the wild relatives of farmed plants and animals and of traditional and rare varieties and breeds seems to be generally of less importance than it is in aquaculture. Moreover in agriculture new candidate species for farming are few, whereas in aquaculture there are probably hundreds. For aquaculture therefore, with its limited history of documentation and development of genetic resources, there is a strong case for assuming that all distinct wild, feral and farmed populations of farmed and potentially farmable aquatic species are potential sources of unique and useful genetic material for aquaculture. However, choices also have to be made among this vast array of genetic resources. Those choices will again be largely influenced by the current choices of consumers as well as the opinions and foresight of researchers and breeders and other actors in the chain.

6. INFORMATION AND NOMENCLATURE

6.1 Crossing communication barriers

Broadly speaking, aquaculture researchers and most fish breeders talk the language of science and understand genetic terminology, whereas many seed producers and farmers and almost all of the general public do not. Inevitably, there is a mismatch between how scientists document genetic diversity in aquaculture and how most seed producers, farmers and consumers perceive, categorize and name farmed fish. The same applies to the conservation of wild populations, for some of which there is a rich folk taxonomy in local languages (e.g. see May, 2005) as well as a rapidly increasing reliance on molecular genetic data (e.g. see Hedrik, 2004).

Common names are the most obvious way through this barrier. FAO uses common names extensively in its provision of fisheries information, including aquaculture statistics. FishBase (www.fishbase.org) provides authoritative and correct nomenclature at species level for finfish, with user entry possible through the scientific names of fish and through their common names in over 200 languages. However, many of the common names listed by FAO, FishBase and others are highly contrived, for the simple purpose of just assigning a name other than a scientific name, which can be daunting to lay users. Therefore many so-called common names are not actually in common use. For example, the tilapia *Sarotherodon galilaeus* is listed by FAO and FishBase as the "mango tilapia", with FishBase suggesting the USA as the source of this common name. This is a beautiful name, but this author has never heard it used anywhere.

More serious problems with nomenclature can occur when the collectors and compilers of aquaculture statistics fail to keep abreast of changes in the scientific nomenclature of farmed aquatic organisms. Taxonomists are constantly revising nomenclature and often disagree about the status of species, which means that at any given time some diversity in nomenclature is inevitable. Recognizing this, the world's taxonomic databases and information systems increasingly allow not only for entry through common and scientific names but also provide coverage of synonyms and common misspellings of the latter to assist users to find the information that they seek, and also to consider correcting their nomenclature thereafter. FishBase has long provided such coverage for finfish and it is also available in global databases such as the Catalogue of Life (www.sp2000.org) and Namebank (www.ubio.org). The phylogenetics database Deepfin (www.deepfin.org) links finfish systematicists as a research coordination network and is a useful source for nomenclatural changes.

Overall, the goal for all concerned with management of information about genetic resources for aquaculture must be to call all farmed aquatic species, as far as is possible, by their correct scientific names. For some widely farmed fish this is not yet done rapidly. For example, the mrigal, an important farmed carp species, is not yet widely listed under its correct name *Cirrhinus cirrhosus.* Where taxonomic revision has involved splitting or lumping species, some statisticians persist in using old and incorrect names which fail to indicate the importance of what have come to be recognized as the same species or as separate individual species. A good example of the former is the widely farmed silver barb, an Asian carp, now properly called *Barbonymus gonionotus*. It was formerly called *Puntius gonionotus* or *Barbodes gonionotus*, names which are still found in some statistics and research papers. However, the main problem here is that some aquaculture statistics still refer erroneously to and list separate data for another species, the Java barb or *Puntius javanicus*, all populations of which are now known to be *Barbonymus gonionotus*.

As a further example of the need to check nomenclature, even in international centres of excellence for research and development, in 1999, a FishBase team checked the correctness of all of the scientific names of plants and animals used by the 16 centres of the Consultative Group on International Agricultural Research (CGIAR), including those entered in its System-wide Information Network for Genetic Resources (SINGER) (ICLARM, 2000). The names used by the CGIAR centres and SINGER were compared with the most authoritative sources available; e.g. the Germplasm Resources Information Network (GRIN) and Species 2000. The results were revealing; for example, 3 183 SINGER names did not match valid names or synonyms in GRIN; 400 names used in the SINGER matched synonyms or known misspellings in Species 2000; and 960 SINGER names had no matches in GRIN or Species 2000. It is vital to check all names entered into statistical and other databases that will be used for making policy and decisions about use and conservation of FiGR. Only then will all synonymies and common missspellings be revealed and understood and databases that use scientific names as entry points be fully linkable. Standardized and correct nomenclature at species and interspecific hybrid levels is the first step, before venturing into intraspecific taxa and molecular genetic terminology, which must also be correct and, as far as is possible, standardized.

6.2 Information sources, gaps and future needs

Substantial information about FiGR for aquaculture has been and will continue to be generated by local studies in the developing world, where over 90 percent of aquaculture is practiced and where most wild and captive genetic resources for aquaculture are located. This is part of the global high importance of local studies as contributions to global inferences with respect to fish biodiversity (Palomares *et al.,* 2003). The International Symposia on Genetics in Aquaculture, begun in 1983, contain a wealth of information on aquaculture genetic research and the most important farmed fish species and commodity groups have their associated substantial and ever-increasing bodies of literature on basic research, production, trade etc., including information on breeding programmes and related genetic research results. Good examples are the International Symposia on Tilapia in Aquaculture (ISTAs) (e.g. Fishelson and Yaron, 1983; Bolivar *et al.,* 2004). However, information on FiGR *per se* in such sources is usually limited and much more is scattered among scientific journals, project reports and other grey literature.

Some of the major contributions to FiGR literature have therefore come from workshops and review papers initiated specifically to collect that scattered information (e.g. Pullin, 1988; Agnèse, 1998; Reddy, 1999; Penman *et al*., 2005). These mechanisms are useful for compiling information about on-farm, captive FiGR and wild, free-living FiGR. They help to bridge the gap that often exists between mainstream aquaculture literature and mainstream nature conservation literature. For species and commodity groups that are relatively new to aquaculture – often because of very recent advances in technology that allow captive breeding and mass production of seed – information on genetic resources and development of breeding programmes tends to be generated and disseminated more slowly than that for seed production and growout. The current status of sea cucumber fisheries, farming and CBF affords an example (Lovatelli *et al.,* 2004).

FishBase (www.fishbase.org) is the world's largest biological database on exploited fish, though it covers only finfish. FishBase is constituted and governed as an international consortium of museums, universities and other organizations, including

FAO. Beyond its ongoing contributions to standardization of finfish nomenclature, FishBase contains only limited genetic data of relevance for aquaculture but is still probably the world's largest compendium of such data in the fields that it has been able to cover so far, including: detailed karyological data for about 200 farmed species; limited electrophoretic population genetics data for about 90 farmed species; and limited quantitative genetics records for 9 farmed species. FishBase also provides online linkages to many other sources of relevant information about aquatic biodiversity, including those emerging as the most important global systems, including the Global Biodiversity Information Facility (GBIF; www.gbif.org) and Ocean Biogeographical Information System (OBIS; www.iobis.org).

FishBase and FAO have provided some information packages on farmed aquatic species, through efforts called respectively "Aquaculture Profiles" and the "Cultured Species Information Programme". The effort by FAO is ongoing, whereas that by FishBase, begun in the 1990s, has remained stalled for almost 10 years. Table 4 summarizes the results of both, with respect to their choice of species and their coverage of genetic resources, by actual content and/or by pointers to other sources of information. Only 7 of these 32 information packages contain any information on genetic resources *per se* and only 14 have some links of a limited nature to other sources of genetic resources information.

A new database, "SeaLifeBase", was initiated in December 2005 to develop for important exploited species of aquatic invertebrates (including farmed crustaceans and molluscs) similar coverage to that provided for finfish by FishBase. SeaLifeBase is being executed from the Fisheries Centre, University of British Columbia, hosted by the FishBase team at the WorldFish Center's facility in Los Baños, Laguna, Philippines and supported by the Oak Foundation. Under its auspices, representatives of global and regional biological databases, including some that cover farmed or potentially farmable aquatic organisms (e.g. for seaweeds, Algaebase; for some crustaceans, www.crustacea.net; for finfish, FishBase; and for some molluscs, www.data.acnatsci.org/obis/) met from 25 to 27 May 2006 at an Aquaspecies Workshop in Los Baños, Laguna, Philippines, to explore greater collaboration, linkages and interoperability, including establishment of a so-called "SeaLife" portal to provide access to all. It will be important for FAO and others providing or seeking information on genetic resources for aquaculture to monitor all such developments in this dynamic field of work.

The world's major aquaculture organizations and networks are also useful providers of information of genetic resources for aquaculture, but largely in a current awareness mode and not as genetic resources databases. For example, the Network of Aquaculture Centres in Asia-Pacific (NACA; www.enaca.org) provides a good current awareness facility under the heading "Genetics and Biodiversity". Similarly "oneFish" (www.oneFish.org), a web-based information system developed by the Support Unit for International Fisheries and Aquatic Research (SIFAR; www.sifar.org) in partnership with FAO, provides through its aquaculture and aquaculture resources pages a section entitled "seeds and genetic resources", linking users to important publications and information about ongoing research and donor programmes. The International Network on Genetics in Aquaculture (INGA; www.worldfishcenter.org/inga) is a useful source of information on the application of genetics in aquaculture and on exchanges of germplasm, especially for some farmed carps and tilapias.

There are many other databases and information systems that provide information on aquatic biodiversity, including those accessible via the World Conservation Union (IUCN; www.iucn.org) and the United Nations Environment Programme/World Conservation Monitoring Centre (www.unep-wcmc.org), but none yet addresses adequately the needs of those seeking substantially aggregated and up to date information on genetic resources for aquaculture. In particular, information about

TABLE 4

Farmed aquatic species for which information packages are currently available through A. FishBase Aquaculture Profiles and B. the FAO Cultured Species Information Programme, with indications of current importance in aquaculture and whether these sources contain and provide links to genetic resources (GR) information. "NR" = no reliable production statistics available

A. FishBase Aquaculture Profiles	Production (t)/ year(s)	No. of countries	+ or- GR info	+ or -GR links
Tilapias: *Tilapia rendalli*	843 (1995)	8	-	-
Sarotherodon melanotheron	NR	5	-	+
Oreochromis shiranus	ca.10 to 20	1	-	-
Carps: *Labeo rohita*	NR	13	+	+
Cirrhinus cirrhosus	NR	11	+	+
Catla catla	NR	11	+	+
Others: *Chanos chanos*	371,075 (1995)			
B. The FAO Cultured Species Information Programme				
Seaweeds: *Laminaria japonica*	4 917 788 (1999)	4	-	+
Molluscs: *Mytilus edulis*	NR	12	-	+
Mytilus galloprovincialis	NR	18	-	-
Perna canaliculata	> 70 000 (2002)	1	-	-
Ostrea edulis	6-7 000 (2002)	12	-	+
Mercenaria mercenaria	> 40 000 (2002)	3	-	-
Crassostrea virginica	NR	3	-	-
Ruditapes philippinarum	236 000 (2002)	9	-	-
Crustaceans: *Macrobrachium rosenbergii*	> 200 000 (2002)	12	-	+
Penaeus monodon	676 000 (2001)	21	-	+
Carps: *Hypophthalmichthys molitrix*	4 100 000 (2003)	6	-	-
Aristichthys nobilis	1 722 832 (2002)	24	-	-
Ctenopharyngodon idella	3 572 825 (2002)	>44	+	+
Cyprinus carpio	4 639 460 (2002)	Many	+	+
Carassius auratus	1 702 778 (2002)	14	+	+
Other finfish:				
Acipenser baerii	NR	12	-	+
Anguilla anguilla	ca. 9 000 (2002)	20	-	+
Argyrosomus regius	231	2	-	-
Dicentrarchus labrax	57 000 (2002)	16	-	-
Ictalurus punctatus	270 000 (1996 for USA only)	6	-	-
Oncorhynchus mykiss	ca. 500 000 (2002)	64	-	-
Psetta maxima	ca. 5 000 (2002)	10	-	-
Salmo salar	>1 000 000 (2002)	17	+	-
Sparus aurata	ca. 90 000 (2002)	18	-	-
Amphibians: *Rana catesbiana*	NR	13	-	-

fish breeding programmes, the status and performance of fish strains, hybrids and other genetically altered forms, and fish gene banks is scattered and of highly variable quality; ranging from unverified claims by private breeders to thoroughly documented national collections (e.g. for common carp in Hungary; Bakos and Gorda, 2001). The CABI Compendium on Aquaculture (www.cabi.org/compendium/ac/index.asp) contains useful summaries on major topics concerning genetics in aquaculture and for some species (e.g. *Crassostrea gigas* and *Cyprinus carpio*) its coverage extends to and well referenced summaries that include genetic resources information. However, this coverage does not yet extend to all important farmed fish species; e.g. Nile tilapia. As with the abovementioned attempts by FAO and FishBase to provide aquaculture species profiles, all such efforts face the problem that different authors choose to give different emphases to aquaculture genetics in general and to genetic resources for aquaculture in particular. Moreover, such summaries require frequent updating in order to provide current information in the fast moving field of aquaculture genetics.

For farmed fish, there is not yet any authoritative publication, comparable to the World Watch List for Domestic Animal Diversity (Scherf 1995) from which reliable world totals of breeds and information on their status can be obtained; neither are there any databases for FiGR comparable to those available online for FAnGR: the FAO — maintained Domestic Animal Diversity Information System (DAD-IS; http://dad.fao.org/home.htm) and the International Livestock Research Institute - maintained Domestic Animal Genetic Resources Information System (DAGRIS; http://dagris.ilri.cgiar.org/dagris/). *In vitro* technologies, especially cryopreservation of fish sperm, are likely to become more widely used for FiGR conservation, as long-term and working gene banks. This will increase the need for online databases through which information about these FiGR can be accessed (e.g. see Kincaid, 2000). The System-wide Information Network on Genetic Resources (SINGER; http://singer.grinfo.net/) of the Consultative Group on International Agricultural Research currently performs this role for PGR, but not for other genetic resources.

Because of these large gaps for information on FiGR, and because remedying them would assist progressive coverage of genetic resources for aquaculture by the FAO and others, proposals were made, meetings held and initial studies done towards a new information network – initially given the working title "Aquatic Animal Diversity Information and Communication System (AADIS)" and later called a "Fisheries Information Network for Genetic Resources (FINGER)" (FAO, 1999; Pettman, 2002; Pullin *et al.,* 2000, 2002). This initiative has not been taken further, and a fresh approach would now seem more desirable in view of the increased capabilities and interoperability of existing global and regional databases and information systems.

The main growth area in information on genetic resources for aquaculture is that of molecular genetics. More and more information about genetic resources will be in the realm of bioinformatics and not at the species level. This already applies to some farmed populations (e.g. Siraj *et al.,* 1998) and to the huge literature on the genetics of wild populations, especially for salmonids where it is greatly assisting conservation efforts as well as leading to better standardization of criteria and indicators (e.g. Waples *et al.,* 2001; Graziano *et al.,* 2005; Verspoor *et al.,* 2005; Utter, 2004). An "SeaLifeBasees Initiative; FISH-BOL" (http://barcoding.si.edu/AllFish.htm) is contributing to the global efforts towards 'barcoding life' for all animal species, based on DNA comparisons for cytochrome c oxidase 1 (www.barcodinglife.com). The main challenge with respect to all bioinformatics is to keep as much information as possible in the public domain and accessible to those in the developing world who need it most. This requires further closing of the digital divide between rich and poor nations.

7. THREATS

7.1 To free-living populations

The world's free-living populations of aquatic species are among its most threatened. Freshwater and diadromous finfish are the world's most threatened species of high importance to humans. Froese and Torres not cited (1999) found that fishes that depend upon freshwater at any stage within their life cycles are 10 times more likely to be threatened than marine or brackishwater species. In 1998, the increasing global threats to finfish, including many species of importance in aquaculture, were the rationale for a major conference convened by the World Fisheries Trust (Harvey *et al.,* 1998). Cowx (2002) ranked recent threats to freshwater fish as follows: alien species introductions; dams and weirs; water quality problems; habitat degradation; overfishing; flow regulation; overabstraction; tourism; mineral extraction; land use change; climate change; predators; poor legislation; and "naïve economic criteria". Freshwater finfish account for at least 65 percent of the world's production of farmed finfish and some of the world's free-living populations of freshwater finfish also comprise its most threatened FiGR for aquaculture, not only in terms of the wild relatives of currently farmed species but also for other species that are potential new candidates for aquaculture or contributors to breeding programmes and related research. Tilapia in Africa (e.g. Piers, 2002) and Chinese carps in the PRC (e.g. Wu, 2003) are examples of major groups of threatened genetic resources for farmed freshwater fish.

The world water crisis poses some constraints for expansion of inland aquaculture and for management of some of its free-living genetic resources, but also offers some opportunities for multipurpose use of scarce water resources, adding value to them and benefits from them. Aquaculture can often be an occupier of water rather than a consumer of water. These potentials remain largely unexplored. Most reviews of the world water crisis emphasize domestic water supply and restrict consideration of the importance of water for food production to its use for growing crops. Where fish are mentioned at all in water resources policymaking, this is usually in respect of allowing for some water to remain available for maintaining aquatic ecosystems and biodiversity, rather than recognizing the huge current contributions and scope for future growth of freshwater food fish aquaculture. Where water scarcity is great, however, threats to free-living FiGR are often unavoidable, as illustrated by the following communication to a tilapia genetics list server (L. Kaufman; February 25, 2006; tilapia@lists.unh.edu):

"…the current drought could be threatening the critical refugium populations of Oreochromis esculentus *and* Oreochromis variabilis *in the Lake Kyoga Basin north of Lake Victoria…………Many are assuming that* O. esculentus *is secure because of the introduced population in Nyumba ya Mungo reservoir, but there is substantial genetic differentiation among the various relict and introduced populations that should not be squandered".*

7.2 To captive populations

Crop and livestock farmers typically discontinue their use of many lower yielding, traditional and minor varieties breeds, for obvious commercial reasons. Their future availability for use in future research and breeding programs is therefore often threatened. For example, 22.5 percent to 32 percent of the world's livestock breeds are thought to be at risk of extinction (Drucker *et al*., 2001; FAO data). The same will apply increasingly in aquaculture, as genetic improvement proceeds. Fish seed producers and farmers will choose to keep mainly or exclusively the latest available strains, hybrids etc. The present extent of this has not been documented, but recent indications of wide adoption of GIFT- and GIFT-derived Nile tilapia strains (ADB, 2005b) suggest that it can be rapid.

7.3 Biosafety and biosecurity

For the near future, selective breeding will probably continue to be the main route to genetic improvement in aquaculture. However, increasing use of biotechnology in aquaculture will increase and will involve both use of and impacts upon FiGR and other biodiversity. It must therefore be approached with high precaution and thorough appraisal prior to commercial use. This is biosafety, in the broad sense and it applies to all farmed aquatic organisms, not only to transgenes. As was agreed at a landmark international meeting (ICLARM-FAO, 1999) the characteristics of any genetically altered farmed aquatic organism and its possible impacts on any recipient environments and biota, on-farm and off-farm, are the important biosafety considerations, not the technique(s) by which it was produced.

Despite the high and increasing importance of aquaculture, no farmed aquatic organism has yet been accorded sufficient priority for genome sequencing. There is a strong case for the Nile tilapia genome to be the first farmed fish genome to be sequenced, as this species has global importance in aquaculture and also serves as a model perciform fish (www.hcgs.uhn.edu/cichlid). Development of transgenic fish is well underway (e.g. see http://www.pewagbiotech.ord/research/fish/). Other genetically altered fish, developed from alien and indigenous species, are widely farmed already; for example, highly selected strains, hybrids, artificial polyploids, and monosex populations.

Pullin *et al*. (in press) found that the proportions of world aquaculture production derived from alien species decreased from about 25 percent in the 1950s to about 15 percent in the 1990s, but pointed out that these data are highly influenced by the huge quantities of indigenous carps farmed in the PRC. On a per country basis, they found that contributions of alien species increased from about 40 percent in the 1950s to 45 percent in the 1990s and that the numbers of alien species used in aquaculture totaled about 40 and were increasing. De Silva *et al*., (2005), in assessing the roles of alien species in Asian freshwater aquaculture to 2002, found that they accounted for over 40 percent of total production based upon data that excluded indigenous carps farmed in the PRC. With PRC data included, their contribution dropped to almost 12 percent. Casal (2006), from FAO and FishBase data for 2000, found that alien species accounted for only 5 percent of the PRC's farmed freshwater fish production of 13 269 693 tonnes, but accounted for 72 percent of the 338 861tonnes of farmed fish produced in Indonesia and 87 percent of the 94 844 tonnes produced in Brazil. It is certain that the use in aquaculture of alien species and of genetically altered forms of both alien and indigenous species will increase. The rapid growth of the farming of Nile tilapia and tilapia hybrids in Asia and Latin America, all developed through original introductions from Africa, and the use of alien Asian species within Asia itself are clear evidence. Consequently, there will be increased movements of farmed aquatic organisms, for production, processing and marketing, as well as for research. This will increase the need for assurance of biosafety, with more effective quarantine and other biosecurity measures. For example, their absence or ineffectiveness and the consequent spread of viral diseases have cost shrimp farming dearly – e.g. white spot syndrome virus, one of four viruses responsible for losses of the order of billions of dollars, cost shrimp farming in Asia (US$4-6 billion) from 1992 to 2001 – and made biosecurity in shrimp farming a growth industry (Lightner, 2005). Specific pathogen-free populations of the Pacific white shrimp (*L. vannamei*) are becoming genetic resources of importance for shrimp farming.

When aquatic plants and animals escape, or are released for CBF, from research or production facilities, they can have serious adverse impacts (interbreeding, competition for food and for spawning sites, spreading disease etc.) on other aquatic organisms, wild and farmed, and can cause permanent changes to the recipient ecosystems. This applies not only to farmed alien aquatic species but also to farmed genetically altered forms of indigenous species. International introductions, transfers within States, and releases for CBF can bring about permanent changes in the status and integrity of other biodiversity and indeed of other genetic resources for aquaculture. The inevitability of increased use of alien species and of a wide range of genetically altered forms in aquaculture therefore increases the urgency for action to undertake long-term conservation measures for important free-living populations of the wild relatives of farmed aquatic organisms and other species of current or potential importance for aquaculture and related research (see 8.c. below).

Recent meetings and declarations indicate that international and national awareness of the need for biosafety and biosecurity is increasing (e.g. NACA/FAO, 2000; WorldFish Center, 2002, 2003; Gupta *et al.,* 2004). However, moving from such declarations to effective countermeasures against current threats and to ensuring more responsible future behaviour among actors involved in aquaculture research and development and the entire aquarium trade is not easy, in developed and developing countries alike. Economic growth is the main basis of development and is almost always antagonistic to fish conservation, as shown recently for the USA in a series of papers and a debate led and published by the American Fisheries Society (Czech *et al*., 2005). Economic growth almost invariably results in widespread losses and degradations of aquatic habitats and reduced aquatic biodiversity.

8. MANAGEMENT

8.1 Concepts and definitions

Management of aquatic genetic resources is full integration of their use and conservation (Pullin, 2000). Conservation of FiGR of actual or future potential use is itself a form of use. Genetic resources can be conserved by one or more of the following options: *in situ/in vivo*, as captive or free-living populations; *ex situ/in vitro,* as gametes, embryos, other tissues and DNA; and *ex situ/in vivo*, as captive populations in research establishments, aquaria, etc.

The Convention on Biological Diversity (CBD 1994) definitions for genetic resources and related terms are followed here, as they are in the mainstream PGR and FAnGR literature. In most FiGR literature, however, use of the terms *in situ* and *ex situ* to describe FiGR is not yet consistent with CBD definitions. According to the CBD (1994), *in situ* conditions are those "*... where genetic resources exist within ecosystems and natural habitats, and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties*"; and *ex situ* conservation is "*conservation of components of biological diversity outside their natural habitats*".

This means that the genetic resources of farmed aquatic organisms that have distinctive properties, and that are held *in vivo* (i.e. as live populations) in their typical farm environments should properly be called *in situ*, as should all wild and feral genetic resources for aquaculture in their typical habitats. The term *ex situ* should be used only for FiGR and aquatic PGR held *in vitro* (e.g. collections of cryopreserved fish spermatozoa, embryos and other tissues) and for FiGR and aquatic PGR held *in vivo* in artificial, off-farm environments (e.g. botanical gardens, aquaria, research establishments and zoos). However, for captive fish populations, the distinction between typical farm environments and these atypical off-farm environments cannot yet be applied as strictly as it can for crop varieties and livestock breeds.

The CBD does not define or elaborate on "distinctive properties". However, for broad categorization of wild and captive genetic resources for aquaculture, it can be assumed that all captive-bred populations of farmed aquatic species have undergone some genetic alteration so as to differ genetically from free-living populations of the same species. The degrees of genetic alteration vary greatly according to with the different histories of farmed aquatic populations with respect to artificial selection, interstrain, interspecifics and intergeneric hybridization, as well as genetic manipulations, including control of sex determination, artificial polyploidy, androgenesis, gynogenesis and transgenesis. Irrespective of all of these purposeful interventions, all captive populations undergo natural selection to hatchery and farm environments.

8.2 *In situ/in vivo*; captive populations on-farm

In situ/in vivo conservation of FiGR on farms is accomplished mostly by seed producers, as broodstock populations. However, there are narrow limits to the diversity of FiGR that can be conserved and used by commercial seed producers and farmers. They must use the bulk of their facilities for holding and selling fish of highly proven viability and profitability, unless compensated specifically to keep other species and strains for conservation purposes. The same applies to FAnGR, for the conservation of traditional and rare breeds of livestock on-farm.

The main requirements for most conservation of FiGR as broodstock on farms, and indeed as *ex situ/in vivo* populations in other facilities (see 7.e. below), are acquisition of founder stocks with high genetic variance and thereafter maintenance of adequate breeding numbers, so as to avoid inbreeding. Broodstock are often not managed well, especially in developing countries. The temptation is to keep only small effective breeding numbers of highly fecund species, such as farmed carps, and to practice *ad hoc* replacement of far less fecund tilapia broodstock from whatever sources are available. Broodstock replacement is expensive. For example, tilapia broodstock used for seed production should normally be replaced within two years of the start of their productive life.

Excellent guides are available for broodstock management and for the selective breeding that it facilitates (e.g. Tave, 1986, 1989; WorldFish Center, 2004a; Gjedrem, 2005). Where farmed fish breeding programmes are well developed, government ministries and research organizations, fish producers associations, certified private sector breeders, and farmers can all work in concert to conserve valuable breeds and to maintain seed quality; for example, in Hungary, 13 breeding farms of the Carp Breeding Section of the Hungarian Fish Producers Association keep 24 certified common carp strains (Váradi *et al.,* 2002).

8.3 *In situ/in vivo*; free-living populations

Free-living, wild and feral, populations of farmed and potentially farmable aquatic species, in inland, coastal and marine waters and wetlands, comprise genetic resources of immense importance for aquaculture. For example, Pullin *et al.,* (2001), from FishBase data, found among the fish fauna of Africa 2 608 unique freshwater species and 842 unique marine species, with over 100 fish species being used in aquaculture and over 1 000 in the aquarium trade. Information about the genetic diversity of some of their populations is increasing together with efforts for their conservation (e.g. Agnèse, 1994, 1998; Ryman *et al.,* 1995; Lévêque, 1997; Miller and Craig, 2001; Collares-Pereira *et al.,* 2002; Abban *et al.,* 2004), but the genetic diversity of many is still very imperfectly known. For example, local populations of marine organisms, particularly invertebrates, can exhibit high levels of cryptic speciation (Thorpe *et al.,* 2000).

Conservation of important free-living FiGR is essentially nature conservation. It depends upon the maintenance of their habitats and prevention of human influences that could cause genetic change, including isolation from aquaculture development, alien species and genetically altered farmed aquatic organisms. Aquatic protected areas can provide this to some extent, though conservation of FiGR for aquaculture is still seldom mentioned as a major reason for their establishment, relative to other reasons given: e.g. increased recruitment of neighbouring capture fisheries (e.g. not cited Shiple, 2004). Moreover, far greater emphasis has been given so far to marine protected areas than to freshwater protected areas for the more important and threatened FiGR for freshwater aquaculture. As Rice (2005) has pointed out, managing fish habitats for conservation purposes must keep pace with the rapid scientific developments and new thinking about ecosystem management. Habitat science *per se* has so far lagged behind ecosystem science.

Pullin (1990) recommended increased emphasis on conservation of fish genetic diversity among the goals of nature reserves and safari parks but, as with protected areas in general, this would not often guarantee the high degree of isolation needed to prevent disruption and genetic change. Important PGR are conserved in relatively small areas of habitats that are kept pristine or near-pristine as sacred groves etc.

(e.g. Okafor and Ladipo, 1992) and the extents to which FiGR are also conserved at such locations should be documented. For a more widely applicable and essentially new strategy, Pullin (2006b) suggested co-financing the establishment and upkeep of FiGR reserves, permanently isolated from all contact with aquaculture and other disturbances, together with the responsible development of other areas of aquatic ecosystems, including aquaculture development.

8.4 *Ex situ/in vitro*; cryopreserved sperm, embryos and tissue/DNA banking

In vitro cryopreservation of fish sperm has been accomplished for many species (Tiersch and Mazik, 2000) and is probably achievable for all farmed fish, though frozen sperm viability varies greatly with species. Cryopreservation of the early embryos of bivalve molluscs and sea urchins is also technically possible. However, the large size and fragility of most finfish eggs and embryos have so far defeated all attempts at their cryopreservation. Despite widespread successes with cryopreservation of farmed fish sperm at aquaculture research institutes and fish breeding centres around the world (for examples, see papers in Harvey *et al.,* 1998), this technology remains little used by fish breeders and seed producers, especially in developing countries. It is the obvious future mainstay for long-term, *in vitro* gene banking of FiGR for aquaculture, including farmed and potentially farmable fish, their wild relatives, and all other to in situ/in useful and potentially useful fish genetic material. Savolainen *et al.* (2006) have reviewed prospects and practices for banking DNA and tissues. This has been conceived mainly for plants, but could be explored for farmed aquatic animals.

Ex situ/in vitro conservation of FiGR is best viewed as complementary to their *in situ/vivo* conservation, as has been the strategy for most of the world's PGR. The World Fisheries Trust (www.worldfish.org) has long pioneered complementary conservation of FiGR as free-living populations and as cryopreserved fish sperm, and undertakes extensive training for this approach in developing countries.

8.5 *Ex situ/in vivo*; captive populations in aquaria and research establishments

Public and private aquaria have great scope for conserving FiGR, but this has not yet been realized to the extent of the role played by zoos in conservation of FAnGR. Wild relatives and rare breeds of livestock in zoos are often managed not only as public exhibits but also as *in vivo* gene banks. The population genetics of farmed fish held in aquarium collections have been little studied. Public and private aquaculture research establishments already play large roles in conservation of farmed fish, as captive populations. The problem here is that maintaining and replacing in vivo fish populations is expensive in terms of facilities, staffing and feeds, fish health care etc. The fish research collections of many universities that undertake aquaculture research and teaching are indeed *in vivo* gene banks, provided that their existence does not end along with the short-term projects for which many accessions are acquired.

The Research Institute for Fisheries, Aquaculture and Irrigation (HAKI) leads Hungary's National Carp Breeding Programme (CBP), in collaboration with the Common Carp Breeding Section of the Hungarian Fish Producers Association, using standard methodology (OMMI). HAKI keeps an *in vivo* gene bank of over 30 strains of farmed and wild common carp (e.g. Bakos and Gorda, 2001; Bakos *et al.,* 2002) Since 2002, however, the government ceased to provide support for HAKI's *in vivo* carp gene banking, which HAKI must now fund from its own budgets. Some 25 private farmers maintain populations of their own strains under the CBP. Farmers receive subsidies if they produce OMMI-approved common carp strains (L. Váradi, J. Bakos and Z. Jeney; personal communications).

A further constraint in many developing countries is that tradition or economic necessity requires some government research institutions to produce large quantities of seed for distribution to farmers. This function can severely limit the availability of facilities for *in vivo* gene banking.

9. SHARING BENEFITS AND COSTS: OWNERSHIP AND USE

9.1 Free-living populations

The CBD gives its Parties national sovereignty over their biodiversity, including FiGR for aquaculture. The CBD also provides for recognition of new countries of origin for populations of farmed aquatic organisms that have acquired distinctive properties outside their native ranges; for example, the distinctive farmed strains of common carp developed in Indonesia. The CBD, together with other international conventions that concern aquatic ecosystems (notably the Ramsar Convention on Wetlands, 1971 and the United Nations Convention on Law of the Sea, 1982) also imposes national obligations on Parties to conserve their living aquatic resources.

Poor countries cannot easily take on the burden of conserving their extensive free-living FiGR for use in world aquaculture without external financial and technical support. Many of the world's important free-living FiGR for aquaculture are owned, and often used, by poor indigenous peoples and local communities, who cannot afford to be their long-term stewards for use by the rest of the world unless adequately compensated. The CBD's Article 8j provides for this in common with other international provisions on human rights (e.g. Posey, 1999). Greer and Harvey (2004) have reviewed some of the limited progress made in implementation of these provisions. There have not yet been any well documented examples of the stewards of free-living FiGR for aquaculture and other users of those FiGR for commercial purposes sharing the costs of conservation and the benefits of use.

9.2 Public and private research

Since the 1980s, developed countries seem to have shifted their public-sector research priorities away from increasing the production of food staples (that, coincidentally, provided useful spillovers to developing countries), putting more emphasis on research on environmental, food safety and various other non-food production aspects of agriculture. This trend may require developing countries to invest more in food production research, becoming more self-reliant (Pardey *et al.,* 2006). At the same time, private research and development of biotechnology for staple food commodities has increased, with a growth in intellectual property rights (IPR) and growing concerns as to how these trends will affect developing countries (Wekundah, 2005; Wright and Pardey, 2006a, 2006b).

Private sector research in biotechnology for aquaculture has also increased, especially in developed countries, and the developing countries where most of the world's fish are farmed will need to increase their own public and private research capacities in this area if they are not to be left behind. However, private ownership of FiGR for aquaculture, through assumption of intellectual property rights (IPR) or other restrictions on use, is still rare. There are no well documented examples of substantial financial returns to researchers who have developed and assumed ownership of specific FiGR for aquaculture and related biotechnology. Ownership rights and restrictions on use of FiGR are usually very difficult to enforce. Farmed fish from different breeding programmes and genetic manipulations often look alike and therefore the provenance of a given farmed fish population *in situ* or in a market place is difficult to determine without costly forensic examinations.

For example, GIFT and GIFT-derived and other improved strains of Nile tilapia all look very similar. Without recourse to laboratory tests, a casual observer of their farmed populations and harvests could say only that they must be genetically improved rather than unimproved fish. Simpler and cheaper genetic marking of superficially similar farmed fish strains, hybrids and other genetically altered forms will likely become available to help their developers to differentiate between legitimate use by those who have signed restrictive use agreements and others who are enjoying pirate use. However, acquiring and enforcing IPR on FiGR for aquaculture as strains, hybrids and other genetically altered forms will remain difficult. Their complexities are increased by the prevalence of public-private partnerships in fish breeding, seed supply and farming. It is common in some developed and in most developing countries for government research establishments, breeding centres and hatcheries to supply genetic material to the private sector and also to act as substantial producers of fish seed, even though this latter function could take significant market share away from private seed producers. This issue has emerged in the public-private relationships associated with tilapia breeding and seed supply in the Philippines (WorldFish Center, 2004b).

It is worth noting, at this early stage of domestication for most farmed fish, that the main traditional and commercial breeds of livestock and pet animals (e.g. the Holstein cow and the Labrador dog) are not privately or even nationally owned. Rather, there is private ownership of and restricted, purchasable access to the progeny of multiple pedigreed strains and to individual sires and dams. Hamilton (1999) found no instances of attempts to claim even national or regional sovereignty over or controlling interests in any livestock breed. Pedigreed fish populations in a single hatchery or farm, and pedigreed fish sires and dams are still very little developed compared to their prevalence in livestock and pet animal breeding, but their development would probably afford a better basis for the acquisition of private rights to and returns from FiGR than attempts to seek patents or other officially recognized IPR on farmed fish strains and other genetically altered forms.

The main requirement for equitable use of FiGR is better organization and oversight of germplasm acquisition and transfers, through Germplasm Acquisition Agreements and Material Transfer Agreements similar to those developed for PGR. Public, private and public-private transfers of FiGR for aquaculture are increasing. Responsible protocols and practices for these are not yet well developed or enforced. The INGA has contributed to improving this situation.

10. STRATEGIC DIRECTIONS

10.1 Increased investment

The growth of aquaculture has outpaced that of all other food production sectors and its high importance and scope for further growth, especially for the benefit of poor consumers and farmers, are clear. Past and present investment in the management of genetic resources for aquaculture fails to reflect this. If this situation continues, it will jeopardize achievement of the potential of aquaculture. Many genetic resources for aquaculture are seriously threatened. Countermeasures require increased investment in their management, to match their economic and social importance.

Effective management of genetic resources for aquaculture almost always has higher costs than are normally encountered with PGR and FAnGR. Setting aside areas of natural ecosystems as off-limits to all forms of disturbance has operational and opportunity costs. Establishing and maintaining *ex situ*, *in vivo* and/or *in vitro* fish gene banks is very expensive compared the costs involved in plant gene banks, and gene banks for FiGR cannot be centralized to the same extents as those for PGR. National, regional and international networks and partnerships, including public-private partnerships, can help in the sharing of costs for and benefits from management of FiGR for aquaculture. For example, in Central and Eastern Europe, the Network of Aquaculture Centres (NACEE; http://agrowebcee.net/subnetwork/nacee/) links 31 institutes from 13 countries, all having strong interests in carp genetic resources (Bakos *et al.*, 2002).

10.2 Management as agrobiodiversity

The whole of agriculture and fisheries and their supportive ecosystems function as a global trophic web. However, aquaculture is farming and has much more in common with agriculture than with capture fisheries. In particular, on-farm *in situ* and all *ex situ* genetic resources for aquaculture merit recognition as part of agrobiodiversity and management, along with PGR and FAnGR, through common policies, institutions and mechanisms.

10.3 Improved information systems

Thorough documentation and accessible information on all categories of genetic resources for aquaculture is an urgent requirement. This means gathering, processing and linking information on free-living genetic resources for aquaculture with that for breeding programmes and related research, with the types of seed supplied to farmers, and with production and value statistics for farmed aquatic species, strains and other genetically altered forms. This can be approached progressively. The genetic resources of the more important farmed aquatic plants could be covered under existing arrangements between the International Plant Genetic Resources Institute (IPGRI) and FAO. It would also be relatively easy to prioritize coverage of the most important genetic resources for farmed food fish. The genetic resources for farmed ornamental aquatic species are a lower priority and will continue to be documented to some extents by the aquarium trade and by databases such as FishBase.

10.4 Conservation in changing ecosystems

The future availability and integrity of free-living and captive genetic resources for aquaculture depends upon the status of their environments; i.e., natural aquatic ecosystems and agroecosystems. Brown *et al*., (1997) made this point thus, with reference to pressures such as fragmentation, and pollution: "*….the goal of conserving appropriate genetic diversity is best achieved not by focusing on maintenance of the genes and genotypes that currently exist within a species, but by trying to prevent drastic alteration in the pace and direction of these evolutionary processes*."

This amounts to a call for ecosystem-based management at the genetic level, on-farm as well as for natural ecosystems. The increasing needs to confront climate change and climatic uncertainties are also highly relevant here. However, much of the literature on ecosystem-based management for fisheries emphasizes the species level, higher taxa and their functions, and pays little attention to genetic resources. An ecosystems perspective that includes the genetic level will show that some losses of genetic resources for aquaculture are inevitable as development proceeds. It is important to recognize this and, by monitoring and understanding the processes involved, to improve prospects for keeping important genetic diversity. What actually can be kept and what will be lost are parts of a bigger picture than genetic resources inventories alone can suggest, and the costs of *in situ/in vivo* conservation and complementary *ex situ/in vitro* conservation are always serious constraints. The conservation of free-living populations and traditional breeds of farmed species is like a battlefield where, distasteful though it is, triage is sometimes inevitable. Complementary *ex situ*, *in vitro* and *in vivo*, conservation is vital for important genetic resources that are seriously threatened *in situ*.

10.5 Reconciliation of aquaculture and nature conservation

Conservation of *in situ/in vivo*, free-living genetic resources for aquaculture have yet to be adequately recognized as part of the rationale for greater investment in conservation of natural aquatic biodiversity and habitats. Many nature conservationists can conceive alliances between agriculture or forestry and conservation but most perceive aquaculture principally or solely as a threat. As more responsible aquaculture becomes the norm, the CBD, IUCN and the Ramsar Convention, together with many nature conservation organizations, especially NGOs, at international, national and local levels, will hopefully find partners within the aquaculture sector itself so as to reconcile and, where possible, to twin their respective goals. FAO and the CGIAR can help this process, but are likely to be more involved with conservation of captive and *in vitro* genetic resources for aquaculture production and related research.

10.6 Progressive linkages with management of FAnGR

Recent meetings and publications (Pullin 2006b; Science Council 2005) have recognized the many lessons to be learned from management of FAnZGR for management of FiGR for aquaculture. For example, there could be much closer linkages with respect *ex situ/in vitro* conservation of FiGR and FAnGR, especially in terms of shared facilities. The main strategy for FiGR here would probably be decentralization, with establishment of and support to relatively small and affordable national and local gene banks, kept within or as close as possible to production areas. Most responsibilities would probably rest with national public sector research establishments, private sector breeders and seed suppliers. The CGIAR would probably not be involved to any extent comparable with its involvement in gene banks for PGR. The WorldFish Center has so far taken only a minor role in this area to date, for GIFT strains of Nile tilapia and for its own collaborative and in-house research. The International Livestock Research Institute is not involved in gene banking for FAnGR, but has collections of PGR for fodder species.

10.7 Exploration of interactive governance and governability

Management of genetic resources for aquaculture is part of the global management of all natural resources. A new approach to this, called interactive governance, is being developed, using capture fisheries as its main model, with some preliminary explorations for aquaculture (Kooiman *et al.,* 2005; Bavinck *et al.,* 2005; Pullin and Sumaila, 2005). Interactive governance recognizes the diversity, complexity, dynamics and scales that are represented in all natural resources that are "systems to be governed". Genetic resources for aquaculture fit this description very well and are therefore subjects for further explorations of the utility of the interactive governance governance approach for their management and for assessments of their governabilities. Research in this general area is being carried out by an international network (www.fishgovnet.org) with a current emphasis on operationalizing interactive governance in capture fisheries, aquaculture and coastal zones, mainly through developing the concept of and methodologies for determining governability (e.g. Chuenpagdee *et al.,* 2005).

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