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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

STATUS AND TRENDS IN AQUATIC GENETIC RESOURCES: A BASIS FOR INTERNATIONAL POLICY

This background study paper is made available to the Commission on Genetic Resources for Food and Agriculture to inform decision-making on future work on aquatic genetic resources, in the context of its Multi-Year Programme of Work.

In May 2006, the FAO's Fisheries and Aquaculture Management Division and the Secretariat of the Commission convened, with the World Fisheries Trust, an international workshop on *The Status and Trends in Aquatic Genetic Resources: a Basis for International Policy*.This document provides a summary of the proceedings and the outcomes of the workshop. Experts in the fields of aquaculture, biotechnology, fishery genetics, international development and policy analyzed the status of aquatic genetic resources, and trends in their conservation and use, in both capture fisheries and aquaculture. The Report of the Workshop and its conclusions identify key policy issues, priorities and implications for the international development community, in particular FAO and its Commission on Genetic Resources for Food and Agriculture in addressing the rapidly evolving needs of the sector. The executive summaries of their presentations are also given in this document.

The Fisheries and Aquaculture Department will publish the full proceedings of the workshop, as part of their Fisheries Proceeding series.

The opinions in this document are the responsibility of the authors, and do not necessarily represent the views of the FAO or its Members.

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1. SUMMARY OF THE WORKSHOP

The workshop, *Status and Trends in Aquatic Genetic Resources: A Basis for International Policy,* was convened in Victoria, British Columbia, Canada, 8-10 May 2006 and attended by a small group of internationally recognized experts in the fields of aquaculture, biotechnology, fishery genetics, international development and international policy. The experts contributed scholarly reviews on the status of aquatic genetic resources and trends in their conservation and use in capture fisheries and aquaculture, and identified key policy issues, priorities and implications for the international development community in general and for FAO and the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA) in particular.

Fish genetic resources (FiGR) comprise all finfish and aquatic invertebrate genetic material that has actual or potential value for capture fisheries and aquaculture. In capture fisheries, both inland and marine, more species are becoming endangered and more stocks overexploited. Aquaculture is expanding rapidly and now accounts for about 50 percent of the aquatic foods that are directly consumed by humans. Although genetic resources and technologies are playing a part in this expansion, they have not yet been used to extents comparable to their use in agriculture.

There is an urgent need to develop international policies for FiGR, and the breadth and complexity of capture fisheries and aquaculture present significant challenges to this process. Policies will need to address the differences between FiGR and other genetic resources, notably those for plants and livestock. These differences are due not only to the relatively recent domestication of most farmed aquatic species, but also to the large numbers of fished and farmed aquatic species and to the diversities of their aquatic environments (from the deep sea to small mountain streams) and of the production systems in which they are captured or farmed.

Policies will need to address current market forces from an increasing human population, increased environmental concerns, and improved efficiency of production and harvest. Other issues include information, management, risks and benefits, investments and awareness. Many issues here are common to both capture fisheries and aquaculture, and addressing these would benefit FiGR use and conservation in both. For example, there is a tremendous lack of information on the status and function of much of the world's FiGR. There are also, however, significant issues that are unique to a given source of fish production; for example, the growing investment opportunities in aquaculture and the problems of governance of capture fisheries in areas beyond national jurisdiction, especially in the deep sea.

Information on FiGR was identified as a key issue. At present, it is incomplete, scattered and unstandardized. For wide use, information on FiGR should be global, authoritative, free and objective.

Although tremendous progress has been made in the genetic improvement, genetic stock identification and genomics of aquatic species, much further work is needed:

- to assess the status of FiGR in capture fisheries and aquaculture;
- to improve the capacities of scientists, technical persons, governments and industry;
- to improve facilities for characterizing FiGR;
- to develop genetically improved farmed types of aquatic species;
- to develop appropriate policy instruments on use and conservation of FiGR;
- to improve general awareness and levels of knowledge about FiGR; and
- to prioritize species, geographic areas, and production systems on which to expend resources for conservation and use of FiGR.

The workshop participants agreed that further prioritization of activities and species on which to work will be required. Nonetheless the following were judged to be of major importance:

- establishing and maintaining a directory of FiGR information sources and databases;

- compiling information on the status of FiGR for important exploited and potentially exploitable aquatic species;
- training in risk analysis with respect to FiGR conservation and use;
- identifying national and local gaps in capacity with respect to FiGR conservation and use, including special and urgent needs;
- creating Technical Guidelines for the Management of FiGR in support of the FAO Code of Conduct for Responsible Fisheries and other international instruments;
- linking existing national facilities with specific expertise in FiGR management at a regional level and creating a directory of these facilities and other service providers for conservation, characterization, genetic analysis and genetic improvement;
- reviewing existing international, regional, and national policy documents concerning FiGR;
- increasing general awareness of FiGR among the general public, resource managers and policy makers; and
- developing case studies of successful genetic improvement programmes and fisheries management that have incorporated genetic principles.

2. BACKGROUND OF THE WORKSHOP

In 1995, the 28th Session of the FAO Conference[1] decided to extend the mandate of its Commission on Plant Genetic Resources to cover all components of biodiversity of relevance to food and agriculture. The result was the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA), an intergovernmental body advising FAO on relevant policies and programmes. The FAO Conference recognized that approaches to plant, forestry, animal and fisheries genetic resources are different and require specialized expertise in each field, and that the implementation of the broadened mandate of the Commission should be step by step. The time has now come for the CGRFA to implement coverage of FiGR.

At its Tenth Session, the CGRFA agreed that its Secretariat, in cooperation with FAO's relevant services, should submit a Multi-Year Programme of Work (MYPOW) to its Eleventh Session so that the Commission could implement its full mandate in the medium and longer term, including work related to fisheries. The Secretariat was asked to prepare a document on the status of the resources and needs of the various sectors, including fisheries. In response, the Fishery Resources Division of FAO and the CGRFA, in collaboration with World Fisheries Trust (WFT), convened a small workshop of internationally recognized experts in the fields of aquaculture, capture fisheries, molecular genetics and genomics, the deep sea, international development and aquatic conservation in order to:

- review the status of trends of aquatic genetic resources and biodiversity in capture fisheries and aquaculture (see contributed papers section); and
- identify policy issues, priorities and implications for the international development community, and specifically for FAO and the CGRFA, with regard to aquatic genetic resources and biodiversity.

3. REPORT OF THE WORKSHOP

The term *fish genetic resources* (FiGR) means all finfish and aquatic invertebrate genetic material that has actual or potential value for fisheries and aquaculture, including culture-based fisheries that rely on release of hatchery-bred seed to the wild. FiGR thus include DNA, genes, gametes, individual organisms, wild, farmed and research populations, species and organisms that have been genetically altered by selective breeding, hybridization, chromosome manipulation and gene transfer. The value of such genetic diversity in food production systems and in ensuring the existence and evolution of natural populations has been well established. However, policies for managing these resources at the

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[1] ftp://ftp.fao.org/ag/cgrfa/Res/C3-95E.pdf.

global level are generally lacking[2]. The report concerns almost exclusively FiGR, but farmed aquatic plant genetic resources such as seaweeds are mentioned where appropriate.

Although the CGRFA expanded its mandate to cover aquatic species in 1995, it has taken over a decade to begin to address relevant issues[3]. Workshop participants expressed a sense of urgency for the development of adequate policies for the sustainable use and conservation of FiGR. In both inland and marine capture fisheries, more species are becoming endangered and more stocks over-exploited[4]. Currently, about 50% of the aquatic foods consumed by humans come from aquaculture[5].

FiGR are valuable not only because of their importance in aquaculture and the need to accelerate genetic improvement of farmed aquatic populations, but also because wild stocks are under threat and declining, and wild gene pools represent and ensure the continued survival of populations and species.

Although there are international and regional institutions and organizations that are contributing to addressing these problems (Table 1), there is no global strategy for the management - i.e., the conservation and use - of FiGR. Specific strategies are required for *in situ* conservation of FiGR on farms and in natural ecosystems, and for *ex situ* conservation of FiGR and as cryopreserved gametes or embryos[6].

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[2] Pullin *et al*., 1999.

[3] Bartley and Toledo this volume; Pullin this volume.

[4] Grant this volume; Smith this volume; FAO 2004, http://www.fao.org/DOCREP/007/y5600e/y5600e00.htm.

[5] FAO 2006. State of World Aquaculture. FAO Fishery Technical Paper No. 500. FAO, Rome.

[6] Pullin this volume.

Table 1. Some international and regional initiatives that address aquatic genetic resources in capture fisheries and aquaculture

Activity	Theme	Results
1985 International Association for Genetics in Aquaculture[7]	Genetic improvement in aquaculture	Numerous peer-reviewed publications and network of geneticists
1992 United Nations Conference on Environment and Development[8]	Sustainable use and conservation of FiGR, plus fair and equitable sharing of benefits	Legally binding International Convention on Biological Diversity; Agenda 21; Jakarta Mandate on Marine and Coastal Biodiversity; Cartagena Biosafety protocols
Development of Genetically Improvedt of Farmed Tilapia, (GIFT)	Use of traditional animal breeding and selection from a diverse gene pool to create faster growing and hardier fish for developing-country aquaculture	Successful, public - funded projects that produced GIFT, and disseminated them in Asia and the Pacific to become the basis of national tilapia breeding programmes; the projects also developed capacity for national breeding programmes in Asia and Africa[9].
1993 International Network for Genetics in Aquaculture[10]	Enhancing research and developing collaborative linkages that could help establish national breeding programs	Facilitated development of fish breeding programmes, exchange of information, assessment of genetic improvement programmes and capacity building.
1995 FAO Code of Conduct for Responsible Fisheries	Sustainable fisheries and aquaculture in an environmentally and socially acceptable manner	Soft law code used by FAO member States et al. for fisheries development and management; Technical Guidelines in support of the Code have been produced for many areas of capture fisheries and aquaculture - not yet for FiGR
1995 FAO Commission on Genetic Resources for Food and Agriculture	Inter-governmental body to formulate policies on genetic resources in, inter alia, capture fisheries and aquaculture	The Commission has not yet addressed FiGR.
2001 FAO Committee on Fisheries' Sub-committee on Aquaculture[11]	Inter-governmental forum to address all issues relevant to aquaculture development and management; its parent body is the Committee on Fisheries	Provides advice to FAO Fisheries Department, but has addressed FiGR so far only in general terms of sustainable use.
2001 European Community Directives on GMO's[12]	Strengthening the legislative framework and risk assessment on the deliberate release of GMOs into the environment and the placing of GMOs on the market.	Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms
2004 ICES Code of Practice on the Introductions and Transfers of Marine Organisms	Code on procedures and risk assess-ment for the introduction of alien species that also includes genetically altered organisms	Code of practice that has been adopted in principle by FAO and FAO Regional Bodies.

[8] http://www.ciesin.columbia.edu/TG/PI/TREATY/unced.html

[9] ADB 2005 An impact evaluation of the development of genetically improved farmed tilapia and their dissemination in selected countries. Asian Development Bank, Manila, Philippines. 124p

[10] http://www.worldfishcenter.org/inga/network.htm

[11] http://www.fao.org/fi/body/cofi/cofiaq/cofiaq.asp

[12] http://europa.eu/scadplus/leg/en/lvb/l28130.htm

3.1 Special characteristics of FiGR and the aquatic environment

In 1995, the 28th FAO Conference[1] recognized that different approaches are needed for managing plant, forestry, animal and fisheries genetic resources. The domestication of most of the aquatic species used in aquaculture has a much shorter history than the domestication of plant and livestock species in agriculture and there are many other unique features of the aquaculture and fisheries sectors with respect to conservation and use of genetic resources. The workshop identified the following special features of aquatic species and FiGR that should be considered in policy development:

- most species of farmed fish have a relatively short history of domestication and genetic improvement;
- some species of farmed fish have reproductive characteristics (very high fecundity and short generation times) that can facilitate rapid genetic improvement;
- the variety of aquatic species that are fished and farmed is very high;
- fished and farmed aquatic species have very diverse life histories including, for example, short- and long-lived species;
- the wild relatives of farmed aquatic species are also important for future breeding programs in aquaculture; and
- some farmed aquatic species that escape from captivity can readily establish feral populations.

The workshop also noted that aquatic production systems, species and environments have the following special features.

- production systems include not only conventional capture fisheries that target wild stocks and aquaculture that is based on farming captive-bred fish, but also culture-based fisheries that are stocked from hatcheries and capture-based aquaculture in which wild-caught fish are fattened;
- some aquatic species that are fished or farmed are used in recreational and ornamental fisheries;
- some aquatic species and their wild populations are seriously threatened with genetic change or extinction;
- distinct types of farmed aquatic species are generally less threatened, but become so as farmers choose to retain only the most recently developed and profitable;
- some threatened and endangered fish species are being targeted by capture fisheries or taken as bycatch;
- the numbers of farmed aquatic breeds/strains/varieties and other types are increasing;
- almost all aquatic species that are hunted and trapped in capture fisheries are wildlife, and are often regarded as common property resources;
- capture fisheries may take place in open access environments or in areas not under national or international jurisdiction, e.g. high seas;
- capture fisheries and aquaculture often impact and are themselves impacted by other users of natural resources, especially inland waters (irrigated agriculture/domestic and industrial use), forestry, human settlements, tourism, and waste disposal;
- *Ex situ* and *in situ* conservation of FiGR are important, but can be difficult and costly;
- aquatic environments in capture fisheries are extremely diverse, from the deep sea to mountain streams, and are also typically difficult to monitor;
- aquatic environments in aquaculture range from highly controlled intensive recirculation systems to open water cage, pen, pond and raceway systems in fresh, brackish and marine waters and in most temperature zones; and

- aquatic environments in capture fisheries and aquaculture are often interconnected; in particular some capture fisheries take place in waters that are transboundary, international, and sometimes beyond the scope of any effective jurisdiction.

3.2 *Drivers* influencing management of FiGR

In order to develop appropriate policies on FiGR, key drivers influencing their management need to be identified. "Drivers" refers to trends that influence the conservation and sustainable use of FiGR. The workshop identified the following key drivers.

Driver 1: *Market forces*

- increased demand for food fish due to human population growth, increased affluence and the many health benefits of fish will increase pressure on farmed and wild populations;
- globalization and competition for markets within and among food production sectors will stimulate competition for aquatic resources and necessitate good marketing;
- competition for inputs, resources and space will force fish production to be more cost-effective and efficient; and
- consumer attitudes to some aquatic food production systems and to some new technologies (for example, genetically improved farmed fish and farming systems that are perceived as environmentally and/or ethically unsound) will constrain their adoption.

Driver 2: *Environmental issues*

- stagnation and decline of capture fisheries due to overexploitation and habitat degradation will force improved management in some cases and increase reliance on aquaculture or alternative foods in others;
- increased environmental awareness on the part of policy makers and the public will result in increased demand for sustainable use of fishery products;
- availability of fresh water will change in response to climate change and the needs of human population growth and development; and
- climate change will alter the potentials for capture fisheries and aquaculture in some areas and FiGR are the basis for sustaining the ability of aquatic species to adapt to changed environments, in nature and in farming systems.

Driver 3: *Production and management forces*

- alien aquatic species and genotypes will present opportunities (increased production and value) and problems (loss of wild biodiversity and habitat);
- because most capture fishery resources have been fully explored and there are few new species or areas available, better management of existing stocks or increased reliance on other food sources will be required;
- improved methods for fishing and farming will enable the sectors to expand;
- issues of sustainability have arisen in both capture fisheries and aquaculture and improved methods of fishing and farming are needed to sustain or expand production;
- scientific advances, particularly in the application of genetic technologies, including genomics, to capture fisheries and aquaculture, will provide opportunities for improved fish production;
- intensification of farmed fish production and harvest systems will produce more food per unit area and require improved breeds and management;
- access to FiGR, benefit sharing and intellectual property rights will influence use and policies; and

- increasing consolidation of farmed fish production systems with feed and seed suppliers is likely to have different effects on large- and small-scale producers.

3.3 Issues influencing management of FiGR

The breadth and complexity of the fishery and aquaculture sectors present significant challenges to the development of international policies on FiGR. Addressing the wide range of issues and special features of FiGR will take time and substantial human and financial resources. The mandate of this workshop was to present an unprioritized range of issues to the CGRFA. Prioritization of species on which to work, geographic areas, and production systems etc. Will be the work of future *fora* convened to develop specific details of the MYPOW or other programmes of work.

The issues presented below concern information, management, risks and benefits, investments, awareness, and policy. Some FiGR issues here are common to capture fisheries and aquaculture; for example, some wild FiGR of importance for both capture fisheries and aquaculture are being overfished. There are also important FiGR issues that are specific to either capture fisheries or aquaculture; for example, the difficulties of capture fisheries governance in high seas and areas beyond national jurisdiction, and the growing investment opportunities in aquaculture.

Issue 1: *Information (see also section 3.4)*

For both capture fisheries and aquaculture, there are gaps in information on the status of FiGR and on trends in their conservation and use. Information is often scattered, incomplete and not easily accessible. Genetic information about fish populations is often limited. Where population genetic data do not exist or are too expensive or difficult to collect, especially in some developing countries, surrogate criteria and indicators can sometimes be developed to predict genetic stock structure or to identify genetically unique populations or strains. For example, within a given species, populations that exhibit different life histories, have different migration times, or inhabit different river basins can be expected to be genetically different.

In capture fisheries, lack of information about fish stocks leads to a lack of regulation and to illegal, unregulated and unreported fisheries (IUU). Information is increasing for a change to ecosystem-based management of capture fisheries, but the importance of FiGR and other genetic resources in ecosystem function are yet not well understood. Most important, existing genetic information on fish stocks is often simply not used in fishery management.

Issue 2: *Management of FiGR*

Capture fisheries and aquaculture share several FiGR management issues. Because of a lack of consensus on global priorities, fisheries development and conservation programmes remain largely divorced from FiGR management concerns. Ownership of and access to FiGR, and sharing the costs of FiGR conservation and the benefits from FiGR use, are also issues for both capture fisheries and aquaculture.

Management ─ i.e., conservation and sustainable use ─ of FiGR is often ignored in capture fisheries. This applies not only to the target species but also to key species for ecosystem function and to bycatch species, which are often more vulnerable to extinction than the target species. Capture fisheries can damage habitats, thereby endangering biodiversity, including marine mammals and seabirds. Capture fisheries can have particularly severe impacts on populations of slow growing or late maturing species.

In aquaculture, objectives of development or of assistance are often not clearly defined, resulting in confusion between farming for local food security and farming for export. The wild relatives of farmed fish have actual or potential value, and are often important as food sources in developing countries, so their stewardship must be adequately compensated. There are at present few international efforts to conserve the wild relatives of farmed aquatic species.

Issue 3: *Genetic risks and benefits*

Capture fisheries confront basic conceptual problems such as the definitions of "population" and "stock" – key concepts in the analysis of genetic risk. In aquaculture, there is a need for cost/benefit analysis of breeding programmes and genetic resources management. The use of alien species and alien genotypes in aquaculture and stocking programmes is unevenly regulated in developed and developing countries alike, and the consequent risks to wild and farmed populations are not quantified. Movement of stocks, introductions and transfers, and interactions between hatchery and wild stocks as a result of escapes or deliberate release have yet to be well analysed in terms of their risks to wild and farmed FiGR. To deal with biosafety issues, genetic risk assessment based on genetic stock identification, especially for culture-based fisheries and capture-based aquaculture, was identified as a high priority. Guidelines or codes of conduct on genetic resource management would be useful in addressing many of the management and risk/benefit concerns.

Issue 4: *Investments and applications*

FiGR conservation and use in aquaculture presents significant investment opportunities. However, genetic improvement strategies in aquaculture, from domestication and selective breeding to hybridization and other forms of genetic alteration, can be applied only where there are adequate resources, in terms of human and institutional capacities and prioritized funding. As aquaculture produces more of world's fish supply, the value of FiGR for farmed and potentially farmable fish is increasing, but this has not yet been recognized in terms of increased investment in their management.

Issue 5: *Education and awareness*

In capture fisheries and aquaculture, decision makers often fail to appreciate the urgency to act before species or valuable stocks/strains go extinct. There is also widespread consumer ignorance of how food fish are produced, and most of the general public have no concept of FiGR.

Many capture fisheries professionals are also unaware of the importance of FiGR. In developed and developing counties, many fisheries policymakers and managers either do not know how to use genetic information when it does exist, or are unaware of its existence.

In aquaculture, professional awareness of the importance of FiGR is relatively high in the developed world and increasing in developing countries, but everywhere there is little public awareness about how farmed fish are bred and sometimes misinformation about the actual and potential applications of genetics in aquaculture (Liu 2007).

Issue 6: *Policy instruments and mechanisms*

While policies on FiGR are lacking or inadequate for most capture fisheries, the problem is especially acute with deep sea fisheries. In aquaculture, advances in molecular biology and genetics are outpacing policy formulation for their application and regulation. Policies regulating use of FiGR and alien species/genotypes, when they exist, are often difficult to enforce. The genetic resources of farmed aquatic plants are a special case, as they are not yet adequately covered by existing instruments for plant genetic resources or as FiGR.

Capture fisheries and aquaculture in general lack adequate FiGR policy instruments, at international, regional, national and local levels. This reflects the ongoing inadequacies of efforts to document and to monitor FiGR and to provide for the sharing of costs for their conservation and of benefits from their use, especially for poor people. In developing countries, inadequate human capacity and infrastructure, including low capacity for risk assessment and management when using genetically altered forms, are especially acute. In general, policy formulation will need to balance a cross-sectoral, multi-disciplinary approach (that addresses poverty alleviation and FiGR conservation) with more focussed approach to address specific topics, such as genetic improvement in aquaculture.

3.4 FiGR information sources and needs

FiGR information refers broadly to genetic characterization (e.g. genetic sequences and other measures of genetic diversity at individual and group levels), breeding histories, performance data, and behavioural and life cycle characteristics. Categories of FiGR information include: DNA; genes; gametes; individual organisms; wild, farmed and research populations; species; forms that have been genetically altered by selective breeding, hybridization, chromosome manipulation and gene transfer; and methods for genetic characterization, FiGR conservation, and genetic improvement.

For wide use by the Members of FAO and others, FiGR information should be global, authoritative, free and objective. At present, much FiGR information is incomplete, scattered and held in diverse formats. No existing databases give adequate coverage to FiGR or consolidate existing information, although there are some excellent information sources for specific topics; for example, FishBase[13] has good coverage of cytogenetics and some population genetics. The National Institutes of Health of the United States of America maintains genomic databases on molecular genetics and bioinformatics[14].

Current FAO datasets on capture fisheries and aquaculture, include very little information on FiGR. The FAO *Species Fact Sheets* on farmed aquatic species contain good information on taxonomic features and natural history, but coverage on their genetics is uneven and often lacking. As the number of farmed fish strains, hybrids, and other genetically altered forms increases in aquaculture, aquaculture statistics will need to capture their relative contributions to farmed fish production and value, as is done for livestock[15]. This would assist both conservation and use of FiGR. Similarly, fuller information on the genetics of wild fish populations would improve their conservation and use as FiGR for capture fisheries and aquaculture.

In order to initiate and develop its coverage of FiGR, the CGRFA can draw upon its long experience with plant, and to a lesser extent livestock genetic resources information that is of importance to FAO member states for policymaking and management. FiGR information is held by diverse groups in the public and private sectors. The CGRFA will have to consider to what extent it might need to become itself a centre for FiGR information that FAO will collect and hold, as well as offering linkages with and portals into FiGR information sources collected and held by others. The latter, decentralized system already exists to a limited extent, but much existing FiGR information has limited accessibility because of non-standardized formats and terminology and its reliability and provenance are rarely well checked.

FAO fish production statistics, from capture fisheries and aquaculture, are standardized and represent official government information, but have almost no information regarding FiGR. For CGRFA coverage of FiGR, the use of other sources of FiGR information that are not the official reports of its Members should not be a problem, provided that information meets the criteria of authoritativeness and objectivity stated above.

The workshop appreciated that gathering, compiling and disseminating information on FiGR will require human and financial resources. Therefore, it will be necessary to convince the collectors and holders of FiGR information— such as international, regional, national and local organizations —, that their FiGR information is useful and that making it more widely available as part of FAO's global coverage of FiGR will be of mutual benefit. Provision of FiGR information and facilitating linkages to FiGR information sources will help the members and partners of FAO to:

- fulfil obligations under international conventions such as Convention on Biological Diversity, FAO Code of Conduct for Responsible Fisheries (see previous footnotes), and the Convention on International Trade in Endangered Species of Fauna and Flora (CITES)[16];

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[13] www.fishbase.org

[14] http://discover.nci.nih.gov/

[15] http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGA/AGA4.htm

[16] http://www.cites.org/

- facilitate better management of their FiGR through shared information and experiences;
- improve the identification and traceability of aquatic produce;
- assist risk assessment associated with the movement of aquatic species and the use of genetically altered species[17];
- secure funding and cooperation from donors and partners; and
- seek compensation for adverse impacts on FiGR.

4. CONCLUSIONS AND RECOMMENDATIONS

Tremendous progress has been made in the fields of fish genetic improvement (Liu 2007; Pullin 2007), genetic stock identification (Grant 2007; Smith 2007) and genomics (Liu 2007). The stage is clearly set for the creation of policies on FiGR that reflect this body of experience and anticipate future global needs, especially in view of the expansion of aquaculture and the decline in many wild aquatic populations. The FAO Fisheries and Aquaculture Department, CGRFA and partners will be expected to play major roles in this area over the next several years.

The material presented in this summary and in the following review papers represents scientific analyses of extremely diverse, complex and sometimes controversial topics. Policies for the management of the world's FiGR will depend on a variety of factors. Work plans of the CGRFA will need to reflect that variety. It is the workshop participants' hope and recommendation that other *fora*, including those organized by the CGRFA, will find this material useful for prioritizing areas for future work, in order to meet global development and conservation objectives. Prioritization will need to consider, *inter alia,* species, production systems, geographic coverage, risks and benefits associated with different technologies, consumer perspectives and ethics.

Pending this prioritization, the workshop participants recommended the following next steps toward developing policy instruments on the use and conservation of FiGR:

- assess the status of FiGR in fisheries and aquaculture;
- identify and fill regional capacity needs for scientists, technical persons, government and industry;
- improve facilities for characterizing FiGR;
- continue genetic improvement of farmed aquatic species;
- improve general awareness and knowledge of FiGR;
- assess existing FiGR policy instruments; and
- explore the twinning (i.e. co-planning, co-financing, co-governance) of aquaculture operations with conservation of wild aquatic genetic resources and related habitats.

These recommendations are elaborated upon below.

4.1 Assess the status of FiGR

FiGR exist "*in situ* and *in vivo"* (as free-living, wild and feral populations, and as captive populations on-farm), "*ex situ* and *in vitro"* (as collections of cryopreserved sperm, embryos and other tissues/DNA), and "*ex situ* and *in vivo"* (as aquarium and research populations). Increasing the amount and quality of information on the status of FiGR could use updatable geographic information systems that incorporate genetic information, including diversity and abundance measures. A consultation on existing databases could be convened in order to assess their ability to incorporate this extraordinary diversity. Several good general information sources exist (Pullin 2007; Liu 2007; Smith 2007), as well

[17] Genetic alteration may be the result of a number of genetic technologies, including hybridization, selective breeding, chromosome set manipulation, genetic engineering and gene transfer.

as specialized databases on key species, e.g. common carp, or groups of species such as Pacific salmon and tilapia. A directory of information sources and databases is needed, and establishing and maintaining such a directory could be suitable roles for the CGFRA and the FAO Fisheries and Aquaculture Department.

The status of important farmed aquatic species groups (including tilapias, carps, catfishes, penaeid shrimps, bivalves, abalones, seaweeds, and freshwater macrophytes) could be compiled, reviewed and synthesised. For marine capture fisheries, the most important groups include small pelagics, reef fishes, elasmobranches, large pelagics, demersals, and diadromous fishes. Important inland capture fisheries groups include those for many of the farmed species (such as carps, catfishes, characins, cichlids and salmonids), as well as many others described under the International Statistical Standard Classification of Aquatic Animals and Plants (ISCAAP) scheme. With such a large array of species to study, clear prioritization and working through partnerships will be necessary. Documentation of the status of FiGR for these groups can link to other information sources such as FishBase[18], the FAO cultured species fact sheets[19] and the FAO Species Identification Programme[20]. Work has already begun on summarizing the information available on salmon and trout genetic resources[21].

4.2 Identify and fill regional capacity needs

Capacity building should be increased to include FiGR characterization and management, breed improvement, analysis of genetic data and training in risk analysis. Well-trained persons are already engaged in characterizing FiGR in fisheries and aquaculture (see, for example, the publications of the IAGA[22]) but they and their organizations merit more support to expand training activities. For example, training in risk analysis techniques would help those developing fish breeding programmes to making good choices of broodstock and genetic improvement techniques to meet their objectives surely and safely.

Regional networks can also play an important role in building and maintaining capacity and communication e.g. Network of Aquaculture Centres in Asia and the Pacific (NACA)[23], and the International Network for Genetics in Aquaculture (INGA). The Southern African Botanical Diversity Network, funded by the Global Environmental Facility (GEF) to improve information and capacity on plants, could be a useful model for regions and organizations requesting support for FiGR. The Network of Aquaculture Centres in Eastern Europe (NACEE)[24] has recently been set up with support from FAO and could be expected to help address capacity building on FiGR, especially as capacity to improve and manage FiGR in carp and other freshwater species of commercial importance is well advanced in several member countries. Gaps in capacity should be examined on a geographic scale to identify any special regional and national needs.

FAO could consider creating Technical Guidelines for the Management of FiGR in support of the CCRF. Semi-technical manuals and scientific publications reviewing basic methods of breed improvement and methods of characterization and management of natural fish populations already exist and could be useful models[25].

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[18] http://www.fishbase.org

[19] http://www.fao.org/figis/servlet/static?dom=root&xml=aquaculture/cultured_search.xml

[20] http://www.fao.org/figis/servlet/static?dom=org&xml=sidp.xml&xp_lang=en&xp_banner=fi

[21] Harvey, Brian in press FAO website.

[22] www.mediaqua.fr/IAGA/web/general_information/index.htm

[23] www.enaca.org

[24] http://www.agrowebcee.net/subnetwork/nacee/

[25] See for example Hallerman, E. 2003. Population genetics : principles and applications for fisheries scientists. American Fisheries Society, Bethesda, Md.

4.3 Improve facilities for characterizing FiGR

New facilities in support of use and conservation of FIGR will not be necessary in all countries. Economies of scale are such that numerous small facilities analyzing small amounts of genetic material may not be economically justifiable. Improvements in transportation and communication are making collaboration among organizations cheaper and easier. Some existing facilities, together with the expertise of their staff, could be linked at the regional level. A directory of service providers for breed improvement, genetic characterization and genetic conservation could be created to facilitate access to expertise and technology and to prevent unnecessary duplication of efforts.

4.4 Improve awareness of FiGR

Awareness of the importance of FiGR remains extremely poor and extends from the general public, to resource managers and through to policy makers. This is not altogether surprising, given the rapid developing state of development of genetics and its poor coverage in some school curricula**,** but it must be remedied as soon as possible. The first steps are to compile a list of target audiences that need specific information, then to identify appropriate channels and formats.

Part of the problem is the inability of many geneticists to communicate clearly about FiGR to the public and to professionals who are not geneticists. It was suggested that a workshop be convened to identify target audiences for learning about FiGR and to explore how best to reach them. This workshop could include participants from FAO, donors, government resource officers, NGOs, and other development groups. The International Development Research Centre of Canada has agreed to provide funding for such a workshop[26].

FAO should consider including an article to increase awareness of the value of FiGR and specifically to discuss the necessity of reporting on breeds/strains/stocks/hybrids in the 2008 edition of the FAO flagship publication, *State of World Fisheries and Aquaculture* (SOFIA). If information on genetic resources is to be provided to FAO, then the FAO Fisheries and Aquaculture Department, with assistance from partners, will need to provide some standardization and guidance on appropriate terminology and reporting. The reviews listed under Status above can also be included in SOFIA and used to improve awareness of policy makers, various commissions, fishery managers, hatchery managers, farm managers, industry associations, NGOs, researchers and teachers[27].

Case studies were proposed as a way of demonstrating the value of FiGR in fisheries and aquaculture. The Network of Aquaculture Centres in Eastern Europe (see footnote 25), the long-standing work on genetic improvement of common carp at the Fish Culture Research Institute in Szarvas, Hungary, and the well-established development, use, dissemination and management of common carp genetic resources in eastern Europe were suggested mechanisms and material for a case study. The history of the development and impact of the Genetic Improvement of Farmed Tilapia (GIFT)[28] tilapia was also suggested (see footnote 7). Compilation of those fisheries that are managed at the genetic stock or strain level, and those farms or areas that report production by breed, would be useful in order to better understand the practicalities, costs and benefits of collecting information on FiGR.

4.5 Assess existing policy instruments

Although FiGR are not well covered by most existing international, regional, and national policies, any relevant policies that do exist should be appraised for their application to FiGR. Specific documents recommended for review were the FAO Code of Conduct for Responsible Fisheries (FAO

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[26] The International Development Research Centre of Canada in collaboration with the World Fisheries Trust (Canada) subsequently convened a workshop, *Sink or Swim: Roundtable on Aquatic Genetic Resources,* Victoria, B.C. September 26/27, 2006. www.worldfish.org.

[27]The United Nations General Assembly recently made a similar request that FAO should look a means to revise marine capture fishery statistics based on stock structure http://daccessdds.un.org/doc/UNDOC/GEN/N04/477/70/PDF/N0447770.pdf?OpenElement

[28] http://www.worldfishcenter.org/reshigh01_3.htm

1995)[29], the Cartagena Biosafety Protocols and their parent, the Convention on Biological Diversity (Secretariat CBD 2000)[30]. General documents on ownership, access and intellectual property rights should also be reviewed, especially the material transfer agreements and germplasm acquisition agreements currently used by INGA[31], the Consultative Group on International Agriculture Research[32] and others. Policy formulation will need to balance an holistic approach involving cross-sectoral and multi-disciplinary policies on such issues as economic development, poverty alleviation, and land use, with more specialized policies on FiGR that would address primarily fisheries and aquaculture; for example, public-private partnerships. The Convention on Biological Diversity develops work plans for types of ecosystems, e.g. inland waters, mountains, and deserts, whereas much of the work of FAO and the CGIAR centres is focussed on geographic areas, climatic zones and specific commodity groups. The CGIAR centre with responsibility for capture fisheries and aquaculture is the WorldFish Center[33]; the CGIAR's Bioversity International[34] acts as a Member-Coordinator for a System-Wide Genetic Resources Programme, which includes some coverage of FiGR.

4.6 Explore the twinning of aquaculture operations and conservation

Aquaculture operations have usually had adversarial relationships with other uses of natural resources, especially nature conservation. This is to some extent unavoidable and it applies also in much of agriculture, forestry and mining etc. With aquaculture now in a rapid phase of growth, particularly in the developing world where most of its FiGR are also located, the time is ripe to explore to what extents aquaculture operations can be planned and conducted in harmony with nature conservation, including conservation of FiGR. Reconciliation between the needs of aquaculture operations and the needs of nature conservation is sorely needed. One approach could be to twin indefinitely the financing and conduct of aquaculture operations with those of nature conservation. This would mean setting aside conservation areas that are off-limits to aquaculture and to all contact with farmed fish and farm waters. Some potential sites for this already exist as nature reserves, sacred groves etc. For aquaculture production, the pay-offs would be not only the survival of threatened wild FiGR of present or likely future importance for breeding programmes, but also a platform from which to argue for permission to use, in designated farming areas, the most profitable species and genetically altered farm types available - as is the case for most of agriculture.

5. SUMMARY OF CONTRIBUTED PAPERS

DEVELOPING POLICIES FOR THE MANAGEMENT OF FISHERY GENETIC RESOURCES

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The large and increasing contributions from aquaculture to world fish supply and the problems of managing effectively capture fisheries stocks that are not well characterized genetically have not yet been recognized in terms of increased investment in making and implementing fish genetic resources management policies. The future of the sector will be influenced by a number of drivers that include

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[29] http://www.fao.org/figis/servlet/static?xml=CCRF_prog.xml&dom=org

[30] http://www.biodiv.org/biosafety/default.aspx

[31] http://www.worldfishcenter.org/inga/

[32] see for example http://www.ciat.cgiar.org/improved_germplasm/mta_breeding.htm

[33] www.worldfishcenter.org

[34] www.bioversityinternational.org

the increasing human population, resource limitations, the need to address broad and complex social issues, intensification of farming and fishing systems, increases in technology, and the recognition of sovereign rights of countries in regards to aquatic genetic resources. The diversity of fish genetic resources may help aquaculture and fisheries adapt to a growing number of constraints, however, these potentials are largely unexplored.

The lack of coherent fish genetic resources management and of policies is becoming a serious problem because the recent rapid expansion of aquaculture and the overexploitation of many capture fisheries have involved irresponsible use of natural resources and lack of consideration of the needs of other sectors, resulting in adverse environmental and social impacts, intersectoral conflicts and unsustainability. A transition to more responsible, sustainable and productive aquaculture and capture fisheries has been called for by Members of FAO and the international community. Its success will depend in large measure upon effective policies to manage genetic resources.

The Preamble to the 1989 edition of the Constitution of the Food and Agriculture Organization of the United Nations defines the common purpose of the Nations accepting the Constitution as:

- raising levels of nutrition and standards of living of the peoples under their respective jurisdictions;
- securing improvements in the efficiency of the production and distribution of all food and agricultural products;
- bettering the conditions of rural populations; and thus
- contributing toward an expanding world economy and ensuring humanity's freedom from hunger.

Within this overall mandate, the Fisheries and Aquaculture Department of FAO promotes sustainable and responsible fisheries, through its work to improve policy, legislative and institutional frameworks, to develop and evaluate technologies in fisheries and aquaculture, to build capacity and to collect and disseminate information on the world's fisheries and aquaculture. In 1995 the FAO Council adopted the FAO Code of Conduct for Responsible Fisheries (CCRF) that has since become the framework and primary mechanism through which Member Governments have addressed the above issues. The vision of the Fisheries and Aquaculture Department is: *A world in which responsible and sustainable use of fisheries and aquaculture resources make an appreciable contribution to human well-being, food security and poverty alleviation.* Working through Governments and appropriate Ministries, the Fisheries and Aquaculture Department acknowledges a focus on fishers and fish farmers. The Committee of Fisheries oversees FAO's policies, programmes and activies on the field.

At the same time the CCRF was adopted, the FAO Conference that decided to broaden the mandate of its Commission on Plant Genetic Resources (now the Commission on Genetic Resources for Food and Agriculture) to cover all components of biodiversity of relevance to food and agriculture, recognized that approaches to plant, forestry, animal and fish genetic resources are different and require specialized expertise in each field, and that the implementation of the broadened mandate of the Commission should be step by step.

These two decisions of FAO governing bodies have set the basis for addressing policy matters related to aquatic genetic resources in FAO. In 2004, at its Tenth Session, the Commission agreed that its Secretariat, in cooperation with FAO's relevant services, should submit to its Eleventh Session a Multi-Year Programme of Work (MYPOW); the Secretariat was asked to document the status and needs of the various sectors, including fisheries.

The future work of the Commission will therefore contribute further work on aquatic genetic resources, taking in particular the Code of Conduct for Responsible Fisheries as the framework for future international instruments. The CCRF is a voluntary, non-binding international instrument that the Members of FAO have pledged to help implement as appropriate and to the best of their abilities. Articles of the CCRF relevant to aquatic genetic resources include:

- **Article 6.2** Fisheries management should promote the maintenance of the quality, diversity and availability of fishery resources in sufficient quantities for present and future generations in the context of food security, poverty alleviation and sustainable development. Management measures should not only ensure the conservation target species but also of species belonging to the same ecosystem or associated with or dependent upon the target species.
- **Article 7.2.2** …biodiversity of aquatic habitats and ecosystems is conserved and endangered species are protected;
- **Article 9.1.2** States should promote responsible development and management of aquaculture, including an advance evaluation of the effects of aquaculture development on genetic diversity and ecosystem integrity, based on best available scientific information
- **Article 9.3.1** States should conserve genetic diversity and maintain integrity of aquatic communities and ecosystems by appropriate management (in particular to minimize adverse impacts from non-native and genetically altered species)
- **Article 9.3.3.** States should …encourage the adoption of appropriate practices in the genetic improvement of broodstock, ….
- **Article 9.3.5** States should, where appropriate, promote research and, when feasible, the development of culture techniques for endangered species to protect, rehabilitate and enhance their stocks, taking into account the critical need to conserve genetic diversity of endangered species.
- **Article 12.8** States should conduct research into, and monitor, human food supplies from aquatic sources …and ensure that there is no adverse impact on consumers.

FAO works in close association with a variety of international mechanisms and agencies relevant to the field of aquatic genetic resources and biodiversity, such as the Convention on Biological Diversity (CBD). The FAO CCRF, as well as policies arising from the Commission, have similar principles with, and are complementary to the CBD. Key sections of the CBD include measures relevant to aquatic genetic resources and biodiversity such as: national planning (Article 6); monitoring status of and threats to biodiversity (Article 7); enhance ex situ and in situ conservation (Article 8 and 9); adoption of measures for sustainable use of biological diversity (article 10); or access to genetic resources (Article 15).

Other key international instruments and mechanisms include CITES, the Ramsar Convention on Wetlands, the United Nations Convention on the Law of the Sea, UNESCO and its International Oceanic Convention. Recently, the World Summit on Sustainable Development, the Millennium Development Goals, and the Millennium Ecosystem Assessment have introduced broad goals into the international development arena. Specific goals have been identified in high priority areas such as Africa.

STATUS AND TRENDS IN GENETIC RESOURCES OF CAPTURE FISHERIES

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Genetic diversity encompasses three hierarchical levels: differences between species, differences among conspecific populations and genetic differences among individuals in a population. While the protection of each of these levels of genetic diversity is essential for achieving sustainable harvests, overfishing, habitat degradation and climate change generally overshadow concerns for genetic integrity. Capture fisheries for freshwater and diadromous species are marginally increasing globally, but capture fisheries for marine species have leveled or are declining. The demand for fishery products remains unabated and will increase as the economies of developing countries improve.

The continuing development of new molecular genetic tools provides high-resolution markers for assessing genetic population structure, for estimating demographic parameters and for providing insights into breeding biology. A growing body of population and evolutionary theory, and new statistical and computer procedures greatly assist in the interpretation of genetic data. Presently, genetic variables are generally not incorporated into ecological or economic models. Future models incorporating genetic data will be tailored to particular situations.

Fisheries in rivers and lakes are largely focused on species with naturally fragmented populations. These species are prone to inbreeding depression in small populations and to hybridizations with introduced divergent strains. Hence, genetic concerns are usually addressed under the framework of conservation biology and theory relating to inbreeding and unintentional hybridization.

Diadromous species support large commercial fisheries in the North Pacific and North Atlantic. These species are especially vulnerable to ecological disturbances because of their complex life-history cycle, which spans freshwater and marine habitats. The loss of between-population genetic diversity through population extinctions in some species is especially acute in areas of human development. The failures of numerous transplanting programmes for many species indicate that local populations are adapted to particular habitats and seasonal events and cannot be easily moved to other habitats.

In the marine realm, the greatest genetic threats appear to be the extinction of genetically unique subpopulations and loss of genetic diversity through declines in abundance by overfishing and climate change. For species or stocks supplemented with cultured individuals, genetic swamping with artificially propagated individuals can reduce the fitness of wild populations.

Numerous international conventions and agreements recognize the importance of maintaining biological diversity, but generally treat genetic diversity indirectly as a component of biodiversity. Four steps provide a framework for conserving genetic diversity: 1) identification of objectives, 2) assessment of genetic risk, 3) identification of reference points and 4) monitoring of progress toward objectives.

ISSUES, STATUS, AND TRENDS IN DEEP-SEA FISHERY GENETIC RESOURCES

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The deep-sea is the largest habitat on earth, covering around 53% of the sea's surface, from the poles to the tropics. The deep-sea region starts at the shelf break at the continental margins, around 200 m, and extends down the continental slope and the continental rise to the abyssal plain at around 6 000 m, and the deep trenches. Deepwater fisheries occur on the continental slopes and on seamounts and exploit resources down to ~2 000 m. The continental slopes cover about 8.8% of the world's surface, an area greater than all the continental shelves and shallow seas, and include the most variable habitats in the deep-sea with canyons, ridges, seamounts, hydrothermal vents, and cold seeps.

Definitions of deepwater fisheries vary geographically, but generally occur at depths greater than 400-500 m; trawl fisheries for orange roughy (*Hoplostethus atlanticus*) and oreos (*Pseudocyttus maculatus*, *Allocyttus niger*, and *Neocyttus rhomboidalis*) occur between 600-1 800 m, while long-line fisheries for toothfish (*Dissostichus* spp.) in the Southern Ocean operate down to ~1 800 m. Landings of deepwater fishes have risen from <0.5 m tonnes a year in the 1960s to >3 m tonnes by the late 1990s, with more than half of the annual catch taken from the Atlantic Ocean, but account for only ~5% of the total fish catch. The landing statistics are likely to be under estimates due to illegal, unreported and unregulated (IUU) fishing operations, and discards of bycatch species. Several deepwater fisheries have been characterized by “boom and bust” cycles. Catches of the armourhead (*Pseudopentaceros wheeleri*) on the North Hawaiian Ridge were estimated to have exceeded 150 000 tonnes a year during the late 1960s to 1970s where today no fishery exists. During the late 1990s a new fishery developed for orange roughy and alfonsino (*Beryx* spp.) in the South Indian Ocean with annual landings rising from <1 000 tonnes, peaking at 39 400 tonnes in 2000, and declining to <5 000 tonnes by 2002. In other regions orange roughy fisheries have been closed to commercial fishing, following a cycle of rapidly rising and declining catches. High catches of orange roughy in some areas have been maintained, at least temporarily, through local scale serial depletion as neighbouring seamounts and hills are fished down.

Deep-sea fishes include a large number of diverse species. Not all deepwater fishes are well described and molecular tools are being used to resolve taxonomic questions of species identity. Species exploited by deepwater fisheries include both shelf species, that extend down the continental slopes, and species restricted to depths >400-500m. Most species are caught by trawls on seamounts and ridges, although line fishing and gillnets, and traps for invertebrates are used; toothfish (*Dissostichus* spp.) in the Southern Ocean are taken by trawl and long-line fisheries. An artisanal long-line fishery has existed for the black scabbard fish *Aphanopus carbo* for more than a century off Maderia, but most deepwater fisheries are relatively new and capital-intensive. A few small-scale deepwater fisheries occur where the shelf is narrow and the fishery areas are accessible by small vessels using drop lines. The sustainable yields from such fisheries maybe only a few hundred tonnes a year, but are important for small island states.

Deepwater fisheries generally target teleosts, with sharks taken as bycatch; only a few target invertebrates. In the North Atlantic deepwater fisheries, 22 species of teleosts 10 species of shark and two invertebrates (the red crab *Chaecon affinis* and the shrimp *Aristeomorpha foliacea)* make up the most important commercial species. Major species associated with seamounts include orange roughy, oreos, alfonsinos, and the roundnose greanadier (*Coryphaenoides rupestris*). A high degree of endemism has been reported for seamount invertebrates and fishes, but many of the targeted fish species have extensive ocean-wide and even cosmopolitan distributions.

As with coastal and shelf fisheries, conserving genetic diversity at the population, species, and ecosystem levels should be major goals for managing genetic resources in wild populations. Genetic issues identified for shelf species are likely to be magnified for deepwater species. Many slope and seamount species exhibit traits such as high longevity, slow growth rate, and late maturity, that make them more vulnerable to exploitation than most shelf species.

Marine fish tend to have higher levels of intraspecific genetic diversity than anadromous species, which in turn are more variable than freshwater species; a trend relating to larger evolutionary effective population sizes in marine fishes. Low levels of genetic diversity have been reported in the Antarctic toothfish *Dissostichus mawsoni*. Marine fishes show less spatial genetic differentiation than anadromous and freshwater species, due to the fewer barriers to gene flow in the marine environment. A negative relationship reported between genetic differentiation and dispersal potential in coastal fishes appears to apply to deepwater fishes. Recent developments with new molecular tools, coupled with new analytical approaches, have revealed finer scale population structure within ocean basins for the Patagonian toothfish *D. eleginoides*, but for many deepwater fishes there is little or no information on genetic diversity within and among regions, and the scale of appropriate management units remain uncertain. Local declines among orange roughy fisheries on neighbouring seamounts suggest that they maybe independent units in the ecological time frame of fisheries management, in the absence of detectable genetic differentiation at small spatial scales.

Directional selection, through size-selective harvesting, has been implicated in changes in life history traits in heavily exploited stocks of shelf species, but has not been demonstrated in deepwater fishes, in part due to the limited time series of appropriate data. The genetic composition of a population can also change over generations due to random events. Changes due to genetic drift are most likely in small populations and are expected to be weak in marine fishes with large populations ($N > 10^7$). However 'sweepstake' events, due to high larval mortalities, can result in a small effective population size (N_e) several orders of magnitude smaller than the census population (N). Low N_e / N ratios have been demonstrated in several shelf species and are equally likely to occur in some deepwater species, and potentially lead to loss of genetic diversity in collapsed stocks

There is a general perception that the risk of extinction is low for commercially important marine fishes due to their large population sizes and wide geographical distributions. Only a few marine fishes have been listed as endangered and fewer appear to be close to extinction. Several traits of deepwater species (long life span, large body size, low natural mortality, and late sexual maturity) make them more vulnerable to extinction than shelf species, in particular those species that aggregate on seamounts. Deepwater fisheries have only been operating in the Northwest Atlantic Ocean since the 1970s, but already several species appear to meet the criteria of being critically endangered. Non-target species, that include teleosts endemic to seamount complexes and elasmobranchs with low reproductive potentials, are also likely to be endangered.

Currently discarded fish waste from processing is used for low value products such as fish-oils, meals, pet foods, and silage. Bioactive compounds may be extracted from left-over fish-frames, internal organs, and invertebrate bycatch species for biotechnological and pharmaceutical applications, offering the opportunity to add value to fisheries. Some compounds derived from fish waste have been identified as potential nutraceuticals. Marine invertebrates that occur around hydrothermal vents may provide enzymes and biochemicals for the biotechnology industries and become target species in the future, raising further issues over exploitation of specialised deepwater habitats.

Genetic resources at the species and ecosystem levels are equivalent to ecological resources for which the management issues are well documented in the fisheries literature. The rapid development, and in some cases rapid depletion, of deepwater fisheries is of major concern to fisheries managers around the world, and has been identified repeatedly at local, regional, and international meetings. ICES have recognised that most exploited deepwater fishes are harvested unsustainably and radical reductions in fleets, in particular trawlers, are required to reduce effort and to conserve vulnerable habitats.

NGOs have expressed concern over the mortality of macro invertebrates taken as bycatch in deepwater trawl fisheries on seamounts, and for seabirds taken in toothfish trawl and long-line fisheries, although mitigation measures have been put in place to reduce the bird catch. The fragile and ancient coral “forests” found on seamounts that are amenable to trawling are quickly reduced to rubble by heavy trawl gear. Improvements to trawl gear and monitoring may allow the operation of deepwater pelagic trawls that avoid contact with bottom features. In the short term, one mitigation measure to protect vulnerable and unique habitats is to close selected areas to bottom trawling.

Many deepwater fisheries occur in high-seas areas compounding the problem of management and regulation. IUU fishing has been widespread in high seas fisheries. Increased surveillance and the introduction of a catch documentation scheme have reduced IUU fishing for toothfish within and outside the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Area in the Southern Ocean. Removal of fisheries subsidies should relieve pressure on deepwater stocks to some extent, but will need to be considered in parallel with other management tools. Regional Fishery Management Organisations (RFMOs) are being developed that cover high seas fisheries, and urgent action is required at the global level, to avoid shifting the deepwater fishing problem from one region to another. The inertia in developing and implementing international fisheries legislation, has lead to NGOs calling for the designation of large scale protected areas, and for a moratorium on bottom trawling.Recent initiatives have seen the establishment of a high seas benthic protected area in the Southern Indian Ocean, with further proposals for a network of large Marine Protected Areas or Benthic Protected Areas in waters around Australia and New Zealand, and in the Southern Ocean.

GENETIC RESOURCES FOR AQUACULTURE: STATUS AND TRENDS

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Aquaculture, the farming of aquatic plants and animals, has grown consistently since 1970, when it provided only 3.9% of world fish supply. In 2004, global production of farmed fish (mainly crustaceans, molluscs and finfish) was over 45 million t, comprising about 32% 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% 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% of farmed fish production comes from Asia, with 67% coming from the Peoples' Republic of China. However, aquaculture is increasing in importance in all developing regions and is expected to provide about 50% 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.

FISH GENOMICS AND ANALYTICAL GENETIC TECHNOLOGIES, WITH EXAMPLES OF THEIR POTENTIAL APPLICATIONS IN MANAGEMENT OF FISH GENETIC RESOURCES

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The successful completion of the human genome project marked the start of a genomics revolution, which has the potential to impact aquaculture and fisheries production and has implications for the future management of fish genetic resources (FiGR). Aquaculture has the potential to compensate for dwindling capture fisheries, but biological and production hurdles must be overcome in order to develop cost-effective and sustainable aquaculture. Diseases are major threats to sustainability, and therefore the disease problems should be given high priority. In addition, important production and performance traits (such as growth rate, feed conversion efficiency, body conformation and fillet yield) must be improved in order to make aquaculture more productive and profitable. Genetic enhancement of farmed fish is needed not only to meet the demands of fish production, but also to ensure profitability.

The analytical genetic technologies most relevant to aquaculture and capture fisheries include: DNA markers, genome mapping, microarrays, and sequencing. DNA marker technologies are not only the basis for genetic linkage mapping, but also for the analysis of genetic resources, strain differentiation, species differentiation, parentage identification, and preservation of genetic diversity and conservation of genetic integrity.

The application of genomics in aquaculture is still at the early stages. For many important species of farmed fish, molecular markers have been developed allowing genetic analysis for FiGR conservation and genetic enhancement of farmed fish. Linkage and physical maps have been developed allowing elucidation of genes responsible for important performance and production traits; genome reagents such as expressed sequence tags have been produced providing material basis for the development of microarray technology.

Studies of the genomes of farmed and fished aquatic species have shown both common and unique characteristics that provide both advantages and challenges. In most cases, the genomes of farmed aquatic species are smaller than or comparable to the human genome. Many farmed aquatic species have high fecundity that provides large full-sib and half-sib families, and this greatly facilitates quantitative trait loci (QTL) mapping. However, the large number of farmed aquatic species tends to dilute genomic research efforts.

The genomics revolution and its impacts on aquaculture are expected to contribute to resolving problems such as diseases, environmental impacts, and low profit margins. The major potential applications of genome technologies, primarily in aquaculture but also to some extents in capture fisheries include: marker-assisted selection (MAS) for genetic enhancement; environmetal improvements through enhanced productivity as well as the development of novel technologies for environment monitoring, development of effective vaccines and their delivery technologies; monitoring antibiotic resistance; diagnosis for fish diseases and for the safety of aquatic produce; accurate identification of fish stocks for capture fisheries management and for their use as FiGR in aquaculture; conservation of FiGR, including protection of endangered species, in response to fish production strategies and consumer interests; and the development and application of transgenic fish technology including, for example, sterilization technology to address concerns about their possible environmental impacts .

A great challenge for aquaculture and capture fisheries is the long-term conservation of FiGR**.** Genome technologies provide new tools for genetic analysis. Innovative DNA marker technologies have opened a broad avenue for the analysis of genetic diversity based on genotypes. Some aquaculture operations still use wild fish seed. For these and for future fish breeding programs, conservation of wild FiGR is important.

The applications of genomics in aquaculture and capture fisheries raise ethical, economic, environmental, legal, and social concerns. The most prominent of these at present relate to the development and use of genetically modified organisms. More research is needed not only to resolve issues related to safety of using transgenic fish, but also to produce novel technologies allowing safe use of transgenic technology.

Public education about genomics and its applications is a key issue. The public is relatively naïve and ill-informed about genomics. Conversely, genomics researchers may not understand the practical needs of aquaculture and capture fisheries or of fish consumers. While information dissemination about genomics to the public is very important, better exchanges of information between genome researchers and aquaculture and fisheries professionals are also essential.

Fish genomics and analytical genetic technologies are reviewed here, with some examples of their implications for FiGR management. Genomics is a highly dynamic research field, currently dominated by human genomics but rapid developments in genomics can afford new opportunities for applications in aquaculture and capture fisheries, particularly in the areas of FiGR conservation and genetic enhancement.