CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH
SCIENCE COUNCIL

CONSERVATION OF LIVESTOCK AND FISH GENETIC RESOURCES

Joint Report of Two Studies Commissioned by the CGIAR Science Council

SCIENCE COUNCIL SECRETARIAT
NOVEMBER 2005

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Science Council Commentary on the Joint CGIAR Study of Conservation of Livestock and Fish Genetic Resources

Background

Genetic improvement of crop plants has been a mainstay of the CGIAR's approach to the enhancement of agriculture and research has been based on an integrated concept of conservation, characterisation and use of plant genetic resources. Programs of research on animal species (preponderantly domestic livestock and fish) have encompassed a number of approaches - such as animal health, sustainable production and farming systems research and ecosystem protection - which have included important elements of research on the conservation and use of animal genetic resources without establishing major programs or a critical scientific mass in these areas. Noting the apparent relevance of these areas to the long term success of integrated approaches to the alleviation of poverty through agriculture, and the growth of new international initiatives in these fields, the Science Council commissioned two companion studies to ascertain the requirements and potential future interventions that the CGIAR may make through research on the conservation, of livestock and fish genetic resources. The Reports were presented to, and considered by, the Standing Panel on Priorities and Strategies during the third Meeting of the Science Council (SC3) in April 2005. This Commentary has been developed on the basis of those discussions and the deliberations of a specific Working Group[1] which considered the Reports, and relevant aspects of the new Priorities, in detail.

The Report

Drs John Gibson and Roger Pullin prepared separate reports on livestock (farm animal or FAn) and Fish (Fi) genetic resources respectively[2]: each report contains 14 recommendations. Then, as required by their Terms of Reference, the authors prepared a joint Executive Summary including 13 joint recommendations.

The Terms of References for the two studies asked for: an overview of the state of conservation of farm animal genetic resources (FAnGR) and fish genetic resources (FiGR); a discussion of issues, challenges and opportunities related to the conservation of FAn and Fi GR, particularly in the light of developments in genomics; past and planned work in the CGIAR and elsewhere relating to the conservation of FAn and Fi GR. The final item was for recommendations on what role, if any, the CGIAR might play in FAn and Fi GR conservation research and related activities in the future.

The Science Council is grateful to both consultants for thorough reports. The key issues for the CGIAR have been clearly identified and possible routes forward enunciated. The research areas and approaches fit squarely within the new CGIAR Priorities for Research and add detail to the development and implementation of the respective areas of research[3]. The Science

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[1] The Working Group was comprised of Mike Gale (Chair), Onesmo ole-MoiYoi, Maggie Gill and Peter Gardiner (secretary).

[2] **FAn** was specified as domesticated animals and, where they are still extant, their wild relatives. **Fi** was taken to include finfish, molluscs and crustaceans, although emphasis was expected on species of major importance to aquaculture (and their wild relatives) and to fisheries in developing countries.

[3] See "CGIAR System Research Priorities 2005-2015" Science Council, Draft of June 2005, especially Priority 1C, Conservation of indigenous livestock; Priority 1D, Conservation of aquatic animal genetic resources; and Priority 2D, Genetic enhancement of selected species to increase income generation by the poor.

Council anticipates that both reports should provide good benchmarks for the current state of FAn and Fi GR and the Science Council will publish the reports, together with this Commentary.

General commentary

It is clear that there are differences in the conservation and use of domestic animals and fish in agriculture that will lead to different approaches within the CGIAR. Both have lagged behind food crops in research and investment. Efforts in FiGR, where domestication is far more recent, have been modest even in comparison to FanGR. We note also some of the dilemmas inherent in present approaches. The potential ethical conflict between maintaining populations of livestock *in situ* and optimising livelihoods of the farmers involved, is one such dilemma.

There are however many similarities that appear to have justified the joint approach to FAn and Fi GR taken by the Science Council. Even more than is the case with plant genetic resources (PGR), it is clear that wild germplasm is vital for genetic improvement of cultivated lines for productivity and profitability. CGIAR improvement programs began for FAn only in the 1990s and the improvement of fish for aquaculture is even less advanced. As with PGR, it is clear that characterisation and conservation and use in genetic improvement are interdependent approaches. However the costs of conducting research are, in general, likely to be higher with FAnGR and FiGR than with PGR, so scarce resources must be focused on the most important wild and cultivated genotypes. There is a clear need for genetic characterisation for both classes of genetic resources: for FAnGR to make informed choices of what should be conserved; and for FiGR - where at present strains and genotypes are recognised in only a few species important to aquaculture - to determine the integrity of fish populations. In both cases an evaluation of alternative and complementary strategies to *in situ* conservation are overdue[4]. It is also clear that policy and legal frameworks are needed in the areas of germplasm and benefit sharing, management and sovereignty for both FAn and Fi GR just as much as for PGR. It is important however, that approaches to conservation and use of Fan and Fi GR do not lose sight of the close linkage with research on livestock farming systems, aquaculture and fisheries, such as those undertaken by ILRI, ICARDA and the WorldFish Center.

These reports are timely. The advances in genetics and genomics that are revolutionising the CGIAR's work with PGR are equally applicable to farm animals and to fish. This is an area in which more direct synergies from comparative approaches may be expected. There is great scope for the research approaches of the CGIAR to complement the normative functions and global program development activities of the FAO for FAnGR and FiGR. The FAO is developing global strategies with member countries to understand and improve the state of FAnGR, including through required research. The CGIAR is developing a strategy for its optimum investment in the genetics technology over the next ten years. It is most appropriate that the CGIAR Centers concerned with livestock and fish research are part of these discussions.

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[4] The Science Council recognizes in the treatment of this subject, and in the development of CGIAR Priorities, that conservation of fish species *in situ* is an integral component of research to enhance the sustainability of fisheries. This Commentary largely focuses on the issues and requirements for aquaculture species more directly akin to Fan GR.

The Recommendations

Conservation in situ and ex situ. The Science Council (SC) agrees that limitations and probable lack of sustainability of *in situ* methods in the longer term[5] require that the CGIAR should understand and, with other actors, particularly FAO, explore global priorities and technologies associated with *ex situ, in vivo* and *in vitro* methods to complement current *in situ* conservation. This will include the development of genebank standards. The SC agrees that the CGIAR Centers will not set up genebanks (other than working collections) themselves but should be equipped to advise NARS on technical, economic, policy and legal issues.

It is vital that these approaches are participatory. Priorities for conservation should derive from working with productionists and, for FiGR, managers with responsibility for fish species of high economic importance. A clear CGIAR policy must be developed to deal with possible conflict between the needs for *in situ* conservation and the livelihoods of farmers, and, for FiGR, between *in situ* conservation and sustainable aquaculture and fisheries.

Conservation of wild relatives: The SC agrees that it is imperative that for both animals and fish that we understand the value and accessibility of wild relatives[6]. For FiGR, an understanding of the contribution of genetically distinct strains and hybrids to sustainability of populations and improved productivity should be a high priority. It is unlikely, however, that the CGIAR will become directly involved in conservation activities for wild relatives.

Assessing genetic diversity of FAnGR and FiGR: The SC agrees that the CGIAR and FAO could work in partnership in development of globally used common assessment protocols (at present lacking for both FAn and Fi) for genetic diversity. The molecular marker data generated must be shared between all actors to ensure that the output is a true international public good.

Genetic improvement: Genetic improvement programs for developing regions should continue at CGIAR Centers, underpinned by clear exit strategies whereby the programs and materials will be eventually transferred to NARS. The SC agrees that CGIAR Centers should not be directly involved with the dissemination of improved FAn or Fi germplasm.

Gene discovery, methods and awareness: The SC agrees that Centers should keep abreast of advances in genomics and play a role in awareness and capacity building. The SC would go further, to expect Centers to partner with advanced research institutes and industry for discovery of key genes for adaptation and transgenic technologies to ensure that they are available for our partner NARS with appropriate guidance. The SC is pleased to note and agrees with the ICLARM-FAO conference that determined that '…the characteristics of the organisms … are more important considerations than the processes used to produce them'.

A pro-poor agenda for genetic enhancement: An international think tank to identify pro-poor genetic modifications, by any means, may be a good idea. However the SC is of the opinion that this should arise from discussions between Centers and FAO rather than being solely a

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[5] The concern here is general, encompassing threats to GR and incentives available for conservation practices in the longer term, however it is being more specifically interpreted here in relation to Fan GR and FiGR in aquaculture. See the following recommendations for wild relatives of fish.

[6] See also Specific Priority 1C in CGIAR System Research Priorities 2005-2015. Science Council, September 2005.

CGIAR initiative. The SC will ensure that these issues are injected into current ethical studies of the CGIAR research and mission.

Development and management of information systems and decision support tools: The SC agrees that the CGIAR should exploit its comparative advantage and its 'honest broker' status in establishing and extending its animal and fish databases for international use. FishBase[7] is internationally recognised but would benefit from increased integration with emerging genetic data on finfish, and possible extension to important invertebrate groups. DAGRIS[8] would benefit from reinvention as a new universally accessible database with corporate ownership by interested CGIAR Centers and with a clear complementary role to FAO's DAD-IS[9].

Global policy and international linkages: The SC agrees that a higher profile for FAn and FiGR within the System is required. It would be desirable to have greater links to the accumulated experience of the CGIAR and international partners gained through research and management of PGR. Noting the current roles of the FAO and IPGRI in continuing and emerging genetic resources issues, the best means of placing increased resources is expected to be through a coordinated effort linking CGIAR research to institutes in Rome. The Systemwide Genetic Resources Program (SGRP) will be central to CGIAR strategy.

Standardisation of terms and definitions: Standardisation of definitions and terms is plainly a vital precursor to any internationally coordinated strategy. This is probably a task which a strengthened SGRP should contribute to jointly with FAO and other key actors.

Concluding comments

The SC agrees that the time is right for the CGIAR to make a modest extension of its efforts in characterisation, conservation and use of GR beyond plants to farm animals and fish. The CGIAR is able to provide objective research support to the international policy and normative functions of the FAO and partners in these fields and to develop methods and approaches as international public goods. Genomics and high-throughput marker technologies will be as important as in PGR improvement and the Centers involved with FAn and FiGR should also be involved in developing the System's genomics investment strategy. A higher profile for FAn and FiGR should include increased resources in Rome, probably with SGRP but certainly maintaining regular interactions with colleagues in the appropriate Divisions of FAO.

The key initial requirement is a clear CGIAR strategy for work over, say, the next five years. This must involve the central Centers - ILRI, ICARDA, WorldFish and IPGRI – together with SGRP, FAO and leading NARS. It is vital that the CGIAR's efforts are part of a rational global system from the outset. The strategy will include implementation of the agreed Recommendations in the FAn and Fi GR reports reviewed here. The SC proposes that it organises and hosts this FAn and Fi GR 'Summit'. The research identified should be incorporated into the CGIAR Research Priorities and the means of implementation described. The strategy should include a provision for a further review of progress in these combined fields, in or around 2010.

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[7] A database of information on finfish species hosted by a Consortium of institutes including the WorldFish Center and the FAO.

[8] DAGRIS is the Domestic Animal Genetic Resources Information System hosted by ILRI.

[9] DAD-IS is an FAO-based communication and information clearing house on domestic animal diversity

CONSERVATION OF LIVESTOCK AND FISH GENETIC RESOURCES

John P. Gibson[10] and Roger S.V. Pullin[11]

The report of a joint study on Conservation of Livestock and Fish Genetic Resources is provided in three parts:

- Chapter I - The combined Summary and Recommendations;
- Chapter II - A report on Conservation of Livestock Genetic Resources;
- Chapter III - A report on Conservation of Fish Genetic Resources.

At the request of the CGIAR Science Council, two studies were undertaken to examine the state of the conservation of livestock and fish genetic resources globally, and to identify potential areas for research and related activities in these fields appropriate to the CGIAR. John Gibson compiled and wrote the report on livestock genetic resources and Roger Pullin that on fish genetic resources. The two studies were carried out simultaneously in late 2004/early 2005. The authors worked together to prepare the combined Executive Summary and Recommendations. Subsequent to the presentation and discussion of the two studies at the Science Council's Meeting (SC3) in Colombo, Sri Lanka in April 2005, the reports have been edited for uniformity by the Science Council Secretariat.

The pages of the joint report are numbered consecutively – but Chapters II and III are self standing, including recommendations, tables and references relating to the individual genetic resources separately.

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CHAPTER I: SUMMARY AND RECOMMENDATIONS

Conservation and genetic improvement of plant genetic resources (PGR) have been major activities within the Consultative Group on International Agricultural Research (CGIAR) since its establishment. Genebanks managed by CGIAR centres hold in-trust collections of approximately 11% of the world's total genebank holdings of crop and other PGR for agriculture. The CGIAR has also played a central role in development of policy related to management of, and access to, PGR. In contrast, the CGIAR had very little activity on conservation or improvement of livestock (farm animal) genetic resources (FAnGR) until the early 1990s and since then CGIAR investment in FAnGR research and development has been a small fraction of that for PGR. CGIAR activity in conservation and improvement of fish genetic resources (FiGR) has lagged even further behind that for FAnGR and remains low. Many factors have contributed to these differences in timing and levels of effort devoted to PGR, FAnGR and FiGR: the emphasis given in the 1960s and 70s to increasing world supply of grain crops to feed the global poor, the threats to PGR from changing landscapes and agricultural practices, the ease and low cost of collection, storage and testing of most PGR, and the proven value of unimproved plant varieties and wild relatives in contributing to genetic improvement of modern varieties.

While there is some overlap in the reasons why efforts placed on FAnGR and FiGR lag behind those on PGR, leading to similar needs and opportunities for future action, there are also some fundamental differences between FAnGR and FiGR, and as they contribute to agriculture and food supply, that lead to different needs and opportunities for future action. For example, the vast majority of FAnGR used in agriculture today are the result of a long period of domestication and isolation from their wild ancestors (that are in several cases now extinct). In contrast, most fisheries harvest wild populations and, with some exceptions, fish farming (aquaculture) uses fish that have been domesticated only recently and to a limited extent. Also, there are very many more species of FiGR than FAnGR.

It is estimated that 70% of the world's rural poor depend on livestock as a component of their livelihoods. Livestock play diverse roles in the livelihoods of the poor, including the building of assets, insurance against unexpected events, recycling of soil nutrients, traction, food supply and income generation. Livestock also supply vital micronutrients that have dramatic effects on child health and cognitive development. Fisheries and aquaculture make critical contributions to food security and livelihood for the poor of the developing world. Fish - meaning finfish, crustaceans, molluscs and other invertebrates - are major suppliers of animal protein, health giving lipids and micronutrients to poor rural and urban consumers.

The characterisation, conservation and use of genetic resources for genetic improvement are interdependent activities that form a continuum along which the CGIAR must consider its strategies. This applies to FAnGR and FiGR and has been amply demonstrated by the CGIAR and partners through characterization, conservation and genetic improvement of farmed tilapia, resulting in genetically improved farmed tilapia (GIFT) and GIFT-derived strains and methods applicable to a wide range of farmed fish.

Some 80 species of livestock contribute to agricultural production, though the top 14 species account for 82% of global livestock production. There is considerable debate about the degree of threat to FAnGR, but it seems likely that approximately 30% of the estimated 6,379 breeds of livestock, are under some degree of threat and that threats to FAnGR in the developing world are rapidly accelerating. About two-thirds of the world's fisheries are fully or overexploited. FiGR from over 4,300 species contribute to the productivity of the world's fisheries - and the restorability of those fisheries that are declining or have collapsed. FiGR are seriously threatened worldwide, especially in inland waters, estuaries and other coastal areas. There are 743 threatened finfish species of which 556 (75%) are freshwater fish.

As with PGR, domesticated FAnGR and wild and domesticated FiGR are the basis for breeding programs and genetic improvement research to improve the productivity and profitability of livestock production and aquaculture. FiGR are also the basis of attempts to enhance fisheries by stocking fish raised in hatcheries or collected from the wild. In some circumstances this can compromise conservation of wild populations and the benefits of fisheries enhancement are not always proven.

Despite their importance in conventional capture fisheries, aquaculture, and enhanced fisheries, FiGR categorized below species level (e.g., hybrids and distinct strains) are not yet identified in most fish production and value statistics and conservation of wild FiGR is not yet a high priority for many fisheries managers. There have been few well-proven examples of loss of genetic diversity through fishing, but losses may be unrecognized because the molecular genetic data needed for characterization and conservation of FiGR in many developing country fisheries are generally lacking. Such data are urgently needed for the incorporation of FiGR conservation into ecosystem-based fisheries management and the establishment and management of aquatic protected areas. Molecular genetic diversity data also have a useful role in characterisation, conservation and utilisation of FAnGR, and collection of such data is more advanced for livestock than for fish. But data for livestock remain incomplete and fragmented and the CGIAR has a key role to play in ensuring that comprehensive global surveys are rapidly completed.

Detailed characterisation of FAnGR is essential for informed choices about which FAnGR to use and may well be important for making informed decisions about priorities for conservation. The preferred method of conservation for FAnGR is *in situ* conservation, and successful *in situ* conservation will require effective genetic improvement to ensure that the livelihoods of the farmers involved are maximised. There remain many unanswered questions about how to establish sustainable *in situ* conservation programs and how to develop and sustain genetic improvement programs for FAnGR in the developing world. There are also many choices of fish species to farm among over 300 species in current use. There are also many more candidates for use, especially among freshwater fish. Most species have short histories of domestication and genetic improvement. There are choices between alien and native species and between herbivorous/omnivorous species, such as tilapia, carps, penaeid shrimps and bivalve molluscs, and carnivorous species such as sea bass, groupers and lobsters. These choices largely determine the sustainability of some aquaculture operations as well as many of their environmental and social impacts. Therefore, for FanGR and FiGR the characterization, conservation and use of FAnGR and FiGR are interdependent elements. The wide availability of accurate and up to date information from all along this continuum of characterisation, conservation and utilisation is essential for development of environmentally sustainable livestock agriculture, aquaculture and fisheries that maximise livelihoods and food security of the poor. The CGIAR has a key role to play in ensuring that information and tools for characterisation, conservation and genetic improvement of FAnGR and FiGR are available through integrated and easily accessible databases and through other methods of capacity development.

Enhanced fisheries rely on wild FiGR, but these can undergo domestication selection or purposeful genetic alteration in hatcheries. Moreover, localized wild fish populations, especially invertebrates, can have high genetic diversity, including cryptic speciation. Such diversity can be irreversibly changed by the stocking of hatchery fish or fish from other locations. The development of responsible enhanced fisheries depends upon precaution, with conservation of FiGR a priority goal.

A variety of factors has caused most agencies to promote *in situ* (i.e., active use in the livelihoods of farmers) conservation of FAnGR as the conservation method of choice. But as yet there is relatively little known about whether *in situ* conservation can be developed in a sustainable way in the longer term. This, along with the accelerating threats to FAnGR have created a need to revisit the role of *ex situ, in vivo* and *in vitro* conservation of FAnGR, along with the technical, social, policy and legal issues related to such conservation. In contrast, it is clear that conservation of FiGR must focus on *in situ* FiGR in open waters, complemented with *in vivo* and *in vitro* (cryopreserved sperm) genebanking, with equitable sharing of costs. The highest priority areas and threatened FiGR are: sub-Saharan Africa for tilapia and African catfishes; East, South and Southeast Asia for carps and Asian catfishes: and Latin America for a wide diversity of freshwater finfish.

Genomic information and technologies are well advanced in several livestock species, providing powerful tools for gene discovery and utilisation. Commercially valuable transgenic livestock have been produced, though regulatory and social issues have deterred companies from releasing such livestock into production systems. Fish genomic information and technology is in its infancy. No farmed fish genome has yet been sequenced. However, a consortium is strongly recommending that the Nile tilapia genome be sequenced, as a model perciform fish and because it is a farmed fish of worldwide importance, especially for the poor. Transgenic fish have been produced for about 20 species of finfish, chiefly to improve growth rate and cold tolerance. The CGIAR is well placed to contribute to policy, biosafety and other issues concerning livestock and fish gene discoveries, and transgenic livestock and fish. The CGIAR is well placed to make direct contributions to gene discovery in FAnGR and related species and to promote such gene discovery by others. The CGIAR should play a facilitating role in exploring the potential for genetic modification of livestock and farmed fish, to contribute to livelihoods of the poor, but the CGIAR is not well placed at present to undertake such genetic modifications. The CGIAR is not at present well placed to be a direct contributor to fish genomics research or to the development of transgenic fish.

There is very little policy and legal framework for the management, sovereignty and benefit sharing of FAnGR, either nationally or internationally. There is a rapidly growing need and demand to develop appropriate policy and legal frameworks. The CGIAR has a key role to play in ensuring an informed global debate and resolution, through supply of accurate research and information. This, the CGIAR needs to undertake in very close collaboration with FAO and other international and national agencies. Overall, the CGIAR needs to explore a broad-based governance approach to conservation of FiGR, regarding this as a catalyst for increased responsibility in fisheries and aquaculture, and prioritizing increased responsibility above fish production *per se,* because the former will ultimately achieve the latter. The CGIAR needs to develop a coherent program in policy and legal frameworks applied to agrobiodiversity generally. To that end it would be sensible to develop a policy unit in Rome working closely with FAO that coordinates the activities and expertise of all CGIAR centres that can contribute to these issues.

In all areas of its work, the CGIAR should work closely with the FAO and other international agencies to maximise the focus of collective efforts and targeting of investments by all parties to priority issues. The CGIAR should work particularly closely with the Commission on Genetic Resources for Food and Agriculture (CGRFA) of the FAO to assist its future coverage of FAnGR and FiGR. The CGIAR also needs to ensure that the activities of its various institutes are highly coordinated and collaborative. The Systemwide Genetic Resources Programme (SGRP) should have a broader involvement in facilitating collaboration across the CGIAR, the setting of priorities with external partners and the raising of funds for large-scale initiatives.

Recommendations for CGIAR Activities in Conservation of Farm Animal and Fish Genetic Resources

Where appropriate, these combined recommendations make reference to the specific recommendations for farm animal genetic resources (FAnGR) and fish genetic resources (FiGR) that appear in the separate reports of Gibson and Pullin respectively. The relevant farm animal- and fish-specific recommendations are identified accordingly.

1. Characterization, conservation and use of FAnGR and FiGR (FAnGR.5, FAnGR.12; FiGR.4)

The CGIAR should recognise that the characterisation, conservation and utilisation of FAnGR and FiGR are interdependent activities that are not logically considered in isolation of each other. The CGIAR should be a strong contributor to strategic research on characterization of FAnGR and FiGR, their conservation *in situ* and *ex situ*, and their use in genetic improvement. The needs and opportunities in developing regions indicate that the CGIAR should be substantially increasing its investment in these activities.

2. *Ex situ* conservation and genebanking (FAnGR.4, FAnGR.7; FiGR.7)

The CGIAR should explore approaches and mechanisms for *ex situ* conservation and genebanking (including *in vivo* and *in vitro* conservation) of FAnGR and FiGR that will complement their conservation *in situ*. This should include identification of research priorities, exploration of possibilities for combining cryopreservation of farm animal and fish genetic material in shared facilities, development of genebank standards, and research on related economic, ethical, legal and social issues.

3. *In situ* conservation (FAnGR.6; FiGR.3, FiGR.7)

The CGIAR should recognise that *in situ* conservation is dependent on sustainable use of both FAnGR and FiGR. For FAnGR and FiGR for domesticated breeds of farmed fish, *in situ* conservation is sustainable only if those FAnGR and FiGR provide the best livelihood option for farmers. For FiGR in fisheries and for the wild relatives of farmed fish, *in situ* conservation depends upon responsible management of the ecosystems that support them, including adequate provision of aquatic protected areas for wild fish. The primary role of the

CGIAR in *in situ* conservation therefore differs between FAnGR and FiGR, but should focus throughout on sustainable utilisation.

4. Conservation of wild relatives (FAnGR.1; FiGR.7)

The CGIAR should work closely with IUCN, FAO and other organizations to review the need for *in situ* and *ex situ* conservation of wild relatives of farm animals and farmed fish and, where necessary, develop appropriate strategies for their conservation. It is unlikely that CGIAR will need to become directly involved in conservation activities, though this should be reviewed.

5. Assessing genetic diversity of FAnGR and FiGR (FAnGR.8; FiGR.3)

The CGIAR should develop a strategy for rapid global assessment of the genetic diversity of FAnGR based on use of molecular genetic markers. It should simultaneously be active in developing, or ensuring that others develop the decision support tools that will be required to use this information effectively. For FiGR, the equivalent strategy is rapid expansion of the generation and sharing of data for molecular genetic markers that can be used to incorporate conservation of FiGR into ecosystem-based fisheries management and the establishment and management of aquatic protected areas.

6. Genetic improvement (FAnGR.10; FiGR.4)

The CGIAR should be a key player in developing sustainable methods and strategies for genetic improvement of livestock and farmed fish in developing regions. The CGIAR should not generally be directly involved in production and dissemination of improved germplasm for livestock and farmed fish.

7. Gene discovery (FAnGR.3, FiGR.8)

The CGIAR has a continuing important role to play in raising awareness, facilitating development, capacity development and active participation in discovery and utilisation of genes that control adaptation and disease resistance in livestock and their wild relatives. The CGIAR currently has little present capacity for similar involvement in gene discovery for farmed fish but should assess opportunities and needs for possible future involvement and develop a clear strategy.

8. Genetic modification (FAnGR.2; FiGR.8)

The CGIAR should contribute to analysis and dissemination of information on farm animal and fish genomics, gene discoveries and transgenic farm animals and fish, as well as to discussion fora on environmental, economic, ethical, policy and social issues pertaining to their use in agriculture, aquaculture and fisheries. For livestock and farmed fish, the CGIAR should develop an international think tank to identify and assess genetic modifications that would improve livelihoods of the poor and to consider all related environmental, ethical and social issues. The CGIAR should not at present undertake its own research on the development of transgenic farm animals and fish, but should review carefully its role in such research if clear and environmentally acceptable opportunities for genetic modifications to improve livelihoods of the poor emerge.

9. Development and management of information systems and decision support tools (FAnGR.9; FiGR.5, FiGR.14)

The CGIAR needs urgently to make a substantial commitment to the development of a database for FAnGR that is comprehensive in terms of species, regions and information content, as well as providing to users a range of tools to analyse and interpret data and aid decision-making. In doing this the CGIAR should work closely with FAO, and the international community generally, in both the design and the establishment and filling of the databases. Establishment and filling of the new database for FAnGR will build on the knowledge gained in developing the existing databases, but will almost certainly require new modes of operation and a more partnership based approach on the part of the CGIAR. For FiGR, the FishBase information system should be the main mechanism.

10. Policy development (FAnGR.11; FiGR.12)

Anticipating the growing debate on management of agrobiodiversity, nationally and internationally, the CGIAR should develop a single research unit from which to contribute to regulatory and policy frameworks for all agrobiodiversity (including plants, livestock, fish, trees and others). That unit should be based in Rome to promote the extremely close collaboration with FAO that will be required and to draw upon expertise gained in dealing with political, legal and human issues during the development of regulatory and policy frameworks for PGR. The unit would work closely with all CGIAR centres and bodies to collate research and information inputs required by FAO and the international community.

11. The FAO Commission on Genetic Resources for Food and Agriculture (FAnGR.4, FAnGR.7, FAnGR.9, FAnGR.10, FAnGR.11; FiGR.13)

In addition to areas explicitly mentioned above and close general collaboration between the CGIAR and FAO, the CGIAR should specifically assist the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA) towards achieving wider coverage of FAnGR and FiGR within the broad context of agrobiodiversity.

12. Coordination of activities within the CGIAR (FAnGR.13, FAnGR.14; FiGR.11)

The CGIAR System-wide Genetic Resources Programme (SGRP) should be substantially strengthened with respect to its coordination and promotion of genetic resources activities beyond those for PGR. In addition to its role in facilitating collaboration and the sharing of information and experience among CGIAR centres, the SGRP is well positioned to coordinate CGIAR collaboration with other agencies in the field of genetic resources. Examples include the organization of workshops, expert consultancies and reports to identify needs and priorities for research, and the facilitation of the development of large-scale, multi-institution proposals. Even where the issues being investigated might appear to affect only a single CGIAR centre at the outset, the CGIAR should encourage centres to work through the SGRP to ensure that the world sees the CGIAR working as a coordinated entity with respect to genetic resources, and also to ensure that all opportunities for involvement of centres are fully explored. The CGIAR should ensure that its activities in FAnGR and FiGR are fully coordinated and cooperative across the CGIAR.

13. Standardisation of terms and definitions

The CGIAR should work with FAO and other organisations to standardize definitions and use of terms related to the conservation of genetic resources related to agriculture, fisheries and forestry.

CHAPTER II: CONSERVATION OF LIVESTOCK GENETIC RESOURCES

John P. Gibson

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Outline

This paper reviews the issues affecting the conservation and sustainable use of farmed animals in the developing world. Emphasis is placed on the role of livestock in livelihoods of the poor with a view to identifying research and development issues that could and should be included in a CGIAR strategy for farm animal genetic resources (FAnGR). The contrast is made with biology and actions applying to plants where this is useful to explain differing levels of past activity and opportunities and needs for future activity in animals and plants. The argument is made that the activity domains of characterisation, conservation and utilisation of FAnGR form an integrated continuum and that it is important for the CGIAR (and others) to develop integrated strategies for research and development, and application across the three domains.

Recommendations for CGIAR action appear in the review where the relevant topic is discussed. Order in the text does not imply a ranking of priorities for CGIAR action.

Notes on terminology

Certain terms used in this report have differing accepted meanings when applied to livestock versus some other areas of agrobiodiversity. Dr Pullin has provided an explanation of meanings in different contexts is the section "Definitions" of his companion report of FiGR. The following are the definitions as used in this report.

***In situ* conservation:** means conservation of livestock through continued use by livestock keepers as part of their livelihood strategy in the original area in which the livestock evolved.

***Ex situ* conservation:** means to conservation through maintenance of live animal populations outside of a livestock production livelihood strategy in the area in which they evolved. (In plants, *ex situ* conservation covers all forms of active conservation in gene banks, whether through seeds, tissue culture, cryopreservation or live plants and trees.)

***In vitro* conservation:** means the cryopreservation of gametes or embryos or somatic cells as sources of germplasm to reconstitute live animal populations at a later date.

The role of livestock in the livelihoods of the poor

It is estimated that 70% of the world's rural poor depend on livestock as a component of their livelihood and it has been suggested that focussing on improving the sustainable livelihoods of these people can do more to reduce poverty than increasing productivity in intensive industrial systems (Livestock in Development, 1999). As access to land and farm sizes decrease, poor farmers increasingly turn to livestock as their main source of income (see Livestock in Development, 1999). In general, the rural poor, especially women, derive a larger share of their income from livestock than do the relatively wealthy (Delgado et al., 1999). Livestock play more diverse roles in livelihoods in the low input systems of the poor than in intensive animal production systems. Livestock are an important means of accumulating and storing capital and in contrast to many crop production systems, provide year round cash flow and food supply. Livestock food products are a readily accessible source of micronutrients essential for proper growth, health and cognitive development. Coupled with the predominant role of women in livestock keeping, livestock keeping disproportionately improves the health and welfare of children. Livestock also provide an essential role of nutrient recycling in the predominant crop-livestock systems and in some systems are also important sources of traction and movement of goods.

The above noted features of livestock contributions to livelihoods of the poor result in livestock providing disproportionate opportunities for poverty alleviation in the majority of crop-livestock systems of the developing world. These opportunities may be further enhanced if ways can be found for poor livestock keepers to benefit from the expected doubling in demand for livestock products in the developing world between 1995 and 2020 (Delgado et al., 1999).

The diversity of FAnGR

Some 80 species of animals are used in agriculture today[12] (see Table II.1, taken from Rege and Gibson, 2003). Of these 80 species, many are not fully domesticated, many are used only locally and many exist as only one or very few breeds or races (see later for definition of breed). The top 14 species account for 82% of global animal food production (FAO, 2000).

An individual animal might carry unique gene combinations or new mutations. However, in contrast to the situation with many plant species, exploiting the unique genetic characteristics of an individual animal is extremely difficult due to long generation intervals, low reproduction rates and the high cost of evaluating the genetic characteristics of a single animal. The unit of diversity in FAnGR is generally, therefore, considered to be a population of animals, usually referred to as a breed. The term breed has no universally accepted definition, but can generally be considered as a population of animals that share certain defining physical characteristics and which are not routinely bred with other populations. At one extreme, a breed in developed countries generally has very clear definitions of and limits to physical characteristics and strict definitions on purity of pedigree, typically regulated by a breed society backed by legal rights to enforce its regulations. At the other extreme, in developing countries a breed is often defined by a fairly broad range of identifying physical

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[12] A small number of species are used primarily or wholly for non-food purposes in agriculture, such as dogs for herding and guarding, donkeys for movement of goods, silk worms for production of silk and horses for traction and movement of goods and people.

characteristics and/or geographical location with no regulation over pedigree other than local tradition and/or geographical isolation (see FAO, 2000, for a more detailed discussion).

The differences in definitions of a breed have often been misinterpreted as implying that breeds in developed countries are more distinct genetic entities than breeds in developing countries. In many cases, however, the opposite may be true since many developed-country breeds originated through a purifying process from relatively outcrossed populations only in the past one to two hundred years, whereas many developing-country breeds have probably existed as discrete genetic entities for several thousand years. It is almost certainly true, however, that despite the general lack of documented evidence, many developing-world breeds have also originated from outcrossing with other populations in relatively recent times.

The World Watch List (FAO, 2000) records a total of 6379 breeds of livestock, most belonging to the top 14 species (see also Table II.1).

The value of genetic diversity

Livestock have been undergoing constant genetic change since first domesticated. Natural and artificial selection, crossing between stocks and replacement of one stock with another stock are inherent features of livestock production systems and constant genetic change is the normal state for FAnGR. In the developed world, the past two hundred years have seen several phases of genetic change. In Phase One, the development of more intensive agriculture and changes in demand for agricultural products in the late 18th and early 19th century led to the stabilisation of many breeds as distinct genetic entities through establishment of breed societies that defined breed characteristics and purity. Breeds very often originated from a regional population that contained diverse genetic origins. In Phase Two, as agricultural systems continued to intensify through the late 19th and early 20th century, breeds better adapted to modern production systems became more widespread and other breeds reduced in numbers, many becoming extinct. In Phase Three, as a smaller number of breeds came to dominate production systems in the middle to late 20th century, modern within-breed genetic improvement programs became widely established, coupled with extensive use of crossbreeding and the rise of breeding companies. The breeding companies often abandoned the concept of breed, creating their own synthetic populations from crosses among existing breeds, and then practicing intense selection for desired characteristics within these new populations.

The small number of breeds that dominate cattle, pig and poultry production systems in the developed world today resulted from this several hundred year process of selection between breeds, crossbreeding and selection within pure breed and crossbred populations. Many of the breeds dominating intensive production systems today were relatively minor, often rare breeds 100 years ago. The existence of extensive genetic diversity was the key factor that allowed the modern highly improved breeds to be identified and improved to their current levels.

In the developing world, historical movements of livestock germplasm have been extensive and have had major positive impacts on productivity. These historical movements were largely south-to-south (i.e. between countries that today form the developing world). Movements of livestock germplasm in modern times have been greatly accelerated by massive increases in communication and ease of transport. Much is heard about the movement of so-called exotic[13] germplasm from north to south. But movements of germplasm from south-to-south have been extensive and probably far greater than north-to-south movements. While there are certainly many instances where movement of germplasm into and across the developing world have been detrimental to farmer livelihoods, many and probably the vast majority of movements of germplasm have had beneficial effects[14]. Movements of germplasm, crossbreeding and within-breed selection in the developing world are all likely to accelerate in the future. The availability of a wide range of genetic diversity on which to draw will be critical to ensure that the developing world has the ability to develop livestock best suited to its physical and social environments and production and marketing requirements; just as it has been in the developed world.

The value of diversity and complexity of systems in developed versus developing world

As noted in the first section of this report, livestock have many more diverse roles in production systems and hence livelihoods of poor farmers of the developing world than in intensive, developed world systems. A consequence is that in a typical developed world production system, the economic value of genetic improvement of most species lies predominantly (>90%) in productivity, plus a small value of survival and reproduction characteristics and occasionally also a small component in disease resistance and/or product quality. Conversely in the low input systems of the developing world, typically very little value (<20%) lies in productivity, with most value lying in adaptation to the environment, survival, disease resistance and other functions such as traction and nutrient recycling. Meeting the needs of developing world production systems therefore typically requires a greater range of genetic attributes. Access to genetic diversity is typically a more important requirement of developing world systems than developed world systems.

Given the more diverse roles of livestock in a typical developing world production system, it is much more difficult to make an accurate assessment of appropriate genetic change for a developing world system than for a typical developed world system. In practice, there are highly developed frameworks for analysis of developed world systems and such systems generally receive advanced analysis to design and optimise directions of genetic change. Conversely, frameworks for analysis of needs in developing world systems are not nearly so

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[13] The term "exotic" correctly means "from elsewhere" but in common usage related to livestock germplasm has come to refer to highly improved breeds from developed countries. The term "exotic" commonly is used in a pejorative sense, implying that the germplasm in question is ill adapted to local needs. While there are many instances of inappropriate use of highly improved livestock germplasm, there are also many examples where such germplasm has been of undoubted benefit to poor farmers.

[14] The debate on benefits accruing to developing world countries from movement of livestock germplasm tends to be highly polarised and often based on assessment by both sides of the impacts of a small fraction of germplasm movements. It is the view of the author of this review, based on personal observation rather than detailed review, that the large majority of movements of livestock germplasm in the past 50 years or so, both north-to-south and south-to-south, have provided very substantial net benefits to the developing world. A detailed inventory and impact assessment of movements of livestock germplasm globally would be a substantial contribution to having a more informed debate. Such inventory and impact assessment will also be important to ensure that the upcoming international debates on access and benefit sharing and regulatory frameworks for management FAnGR are well informed. GTZ and FAO have commissioned a small review of international movements of livestock germplasm with selective case studies focusing on a few regions and species. From the results of this study, due in mid-2005, it should be possible to determine the need for and value of more extensive documentation and impact assessment.

well developed[15]. Livestock production systems in the developed world tend to receive low grade or no analysis of needs before genetic change is recommended or imposed. This has often contributed to threats to both livelihoods of the poor and the diversity of the livestock they rely on (see below).

Sources of threats to diversity of FAnGR

The major threats to livestock genetic diversity result from systemic, regional and global economic forces and changing agricultural practices. Intensification of production systems, including the wider availability of vaccines and therapeutics against endemic diseases promote the use of higher-production, less well adapted genotypes (new breeds or crossbreeds) and in some cases change of species. Crossbreeding to a more productive breed from elsewhere, most often a high production breed from a developed country, is widespread and can destroy the purity of an indigenous breed within a single generation. Recovery from such loss of purity can be extremely difficult requiring many generations of backcrossing to purebred indigenous animals. In some cases recovery is impossible because no purebred animals remain to allow a backcrossing recovery program. Indigenous breeds can also be lost during intensification of animal production when concentration of animal production in large intensive units makes smallholder or pastoral farming of indigenous breeds uneconomic.

Apart from overarching economic forces, national and international policy generates significant threats to diversity of FAnGR. A variety of policies may disadvantage poor farmers, effectively forcing them and the livestock they traditionally use out of food production. Not infrequently crossbreeding is promoted as part of national policy or is driven by development agencies of developed countries that often have a requirement to spend much of their development budget at home. Purchase and dissemination of their own breeds is one mechanism for fulfilling that requirement. Crossbreeding has often been promoted by policy in the absence of clear evidence that crossbreeds or new breeds will enhance rather than damage the livelihoods of poor farmers. This is not to say that all such crossbreeding has been or is harmful as some observers would suggest. There are very many examples of crossbreeding promoted by national governments, development agencies, NGOs and private companies that have delivered undoubted benefits to the farmers involved. Thus threats to livestock genetic diversity can result from improvement of the livelihoods of poor farmers or be coupled to threats to their livelihoods promoted by inappropriate introduction of new breeds or crossbreeds or intensification of livestock agriculture making their livestock production uneconomic.

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[15] In 1999 the FAO convened a workshop jointly with the CGIAR to review methods available for valuing livestock genetic resources for purposes of both conservation and utilisation. As a result of this workshop ILRI undertook a program of research with collaborators to investigate and test the suitability of various methods of value assessment in developing world livestock systems. The results of this research were published as 10 papers in a special issue of Ecological Economics, 2003, volume 45. A comparison of methods used for PGR and FAnGR is currently underway. On a small scale, this process is a model of how the CGIAR should operate. The CGIAR worked closely with FAO to identify research needs. The CGIAR then took leadership in developing the required research through partnerships, and the results were then published in a way that maximised potential impact beyond the immediate research domain (in this case many of the methods developed and assessed should be of value to plant, wildlife and ecosystem assessment).

In addition to the long-term global processes providing threats to livestock diversity, short-term local factors can have significant impacts. Examples include the effects of war, drought and famine.

The extent of threats to diversity of FAnGR

While the existence of threats to FAnGR is generally accepted, debate remains about the severity of the threats to FAnGR. Since the turn of the last century, some 16% of uniquely adapted breeds are estimated to have gone extinct (Hall and Ruane, 1993). The World Watch List compiled by FAO lists 32% of breeds of livestock at risk of becoming extinct (FAO, 2000). In Africa, some 22% of indigenous cattle breeds have become extinct in the last 100 years and 27% of the remainder are at varying degrees of risk (Rege, 1999).

The most widely quoted estimates of breed diversity and threats are those of the World Watch List of FAO and these have been widely criticised (though rarely in writing) as being highly biased upwards. The argument is that the FAO intergovernmental process of registering official data results in what is essentially the same breed appearing as many breeds. Many breeds originally imported from their centre of origin may be listed as rare or endangered in the importing country, while the original population or derived populations elsewhere remain uncontaminated and not threatened. The process of breed definition artificially inflates both the total number of breeds and the number of breeds under threat. The process is most noticeable in Europe and the developed world where extensive movement of livestock has promoted a large diversity of breeds which likely reflects a much lower underlying genetic diversity. This viewpoint may also in part reflect the fact that in most of the developed world a variety of privately and publicly funded and operated conservation measures are in place and few breeds of historical, social or physical importance are now considered to be severely threatened with extinction.

Box II.1: Accelerating threats to FAnGR: the case of Red Maasai sheep[1]

The Red Maasai sheep, renowned for its hardiness and disease resistance, especially its resistance to gastrointestinal parasites, is predominantly kept by Maasai pastoralists as well as by the neighbouring tribes in the semi-arid regions of Kenya and Tanzania. A number of research projects have demonstrated the high resistance to diseases (Davies 1987; Wanyangu et al. 1993; Baker et al., 1998), and high productivity under extremely challenging environments where other breeds, such as the introduced Dorper do very poorly (Baker et al., 2002). Until the mid 1970's, purebred Red Maasai were ubiquitous throughout the pastoral lands of Kenya, probably numbering several million head. In the mid 1970's a subsidised dissemination program for Dorper rams was established in Kenya. Widespread indiscriminate crossbreed followed. No instruction was supplied to farmers about how to maintain a continuous crossbreeding program and many farmers continued crossing their flocks to Dorpers, which subsequently proved unsuitable in many production areas. By the time ILRI attempted to establish a research flock in 1992, it took nearly two years search in Kenya and northern Tanzania to find sufficient purebred Red Maasai to establish a 150 ewe flock, and there was some contamination even in the 150 ewes eventually purchased. The breed is clearly threatened, but due to lack of data, the livestock databases DAD-IS (http://dad.fao.org/home.htm) and DAGRIS (http://dagris.ilri.cgiar.org/dagris/) do not identify the breed as threatened and the breed does not appear in the FAO World Watch list (FAO, 2000).

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[1] Edited from A.M. Okeyo, personal communication

While the above arguments about upward biases in estimates for developed countries are probably correct, there is concomitant poor and inaccurate recording and reporting from the developing world that has led to a substantial proportion of threatened breeds in the developing world not appearing on the World Watch List. In addition, although no clear documentation exists, there is a general observation among scientists working on FAnGR in the developing world that threats to FAnGR diversity in the developing world have greatly increased in recent decades and that rates of loss in some regions are considered alarming. An example is provided by Red Maasai sheep of East Africa (see text box II.1). The highly adapted Red Maasai sheep are still widely referred to as the common, widespread and characteristic breed of the East African savannahs of Kenya and Tanzania. But between the mid 1970s and late 1980s the breed was almost eliminated by cross breeding promoted by national governments. As another example, Ankole cattle were until the late 1980s widespread and not endangered in Rwanda and Burundi and Tanzania, but were all but eliminated during the genocide in Rwanda and Burundi and by crossbreeding in Tanzania. They remain secure for the present as a genetically pure population only in Uganda.

A rigorous assessment of the level of threat to FAnGR is prevented by the general lack of high quality and longitudinal data on the FAnGR of the developing world. The assessment of many donor agencies and developed countries has been that threats are overestimated, but this assessment largely results from the problems of recording breed definition and status in the developed world coupled with the relative security of most important breeds of developed countries. Conversely, there are strong indications that the threats in the developing world are substantially higher than existing lists would suggest. Indeed there is a reasonable probability that the developing world FAnGR are already in undocumented crisis. Given the rapidity with which a FAnGR can be lost and the long time taken to effect action to conserve FAnGR, it seems prudent to assume that the FAnGR of the developing world are already in crisis.

The conservation of wild populations and related species

For a number of the major livestock species the ancestral species or sub-species that was originally domesticated is now extinct. Where such wild ancestors still exist, there are few recorded instances of wild populations having been used successfully in genetic improvement programs in recent history[16]. Wild relatives are, however, of undoubted value in gene discovery programs. Wide crosses between domestic breeds and wild or feral relatives provide a powerful resource for mapping genetic changes acquired during domestication and also for identifying useful genetic polymorphisms lost during domestication and subsequent selection (Andersson, 2001). Such polymorphisms might prove useful in future genetic improvement schemes, although there are substantially greater limitations to the value of this approach than with plants (see below). Wild or feral relatives may also possess unique attributes that make them useful metabolic and physiological models of mammalian biology and human health[17].

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[16] Although not truly a wild ancestor, feral pigs have been used in breeding programs to establish lines of miniature pigs (Mayer and Brisbin, 1994).

[17] A population of feral pigs isolated on a remote island for the past 500 years has also been used as a model of mammalian biology, exhibiting a range of extreme adaptive traits such as high salt tolerance and extremely high body fat content, acquired or enhanced during natural selection to the feral state (Mayer and Brisbin, 1994).

Although no documented evidence was collated or identified for the current review, it seems likely that populations of the majority of surviving wild ancestors of most domestic species have been conserved either in zoos or in natural reserves. The motivation has been one of general curiosity and desire to conserve biodiversity in general rather than the expectation that such germplasm might prove useful in genetic improvement of their domesticated relatives. Neither the CGIAR nor FAO nor other traditional CGIAR partners appear to have played any significant role in this conservation.

A number of factors that distinguish animals from plants contribute to the difference in perceived value of wild relatives for genetic improvement of agricultural species. In particular; a) animals are relatively expensive and often difficult to assess for important characteristics and consequently few wild populations have been accurately assayed for useful genetic traits; b) until the relatively recent fragmentation of the wild environment, animals tended to be fairly mobile promoting relatively low levels of population diversity over large areas; c) introgression of useful characteristics from a wild or feral stock into an improved stock is a long and expensive process requiring that the improving genetic characteristics have very substantial effect in order to compete with existing stocks; d) in some species, there are social and legal barriers to acceptance of a new stock with introgressed genes (e.g. definitions of breed purity would make use of novel germplasm introduced through backcrossing very difficult in many cattle production systems).

The above limitations to the ability to exploit genetic attributes of wild relatives within species notwithstanding, there remains the possibility of exploitation of useful genetic characteristics through conventional breeding in the future. (See also the possibility of non-conventional routes for utilisation in the next section.) Such exploitation most likely might apply to wild relatives of smaller species that have high reproduction rates and short generation intervals, where introgression of useful genes is a feasible competitor to existing genetic improvement. Coupled with the value of wild relatives for gene discovery relevant to both livestock production and human health, it seems prudent that the CGIAR be able to demonstrate that the germplasm of wild relatives has been secured for the future. And where not secured, that plans are put in place to secure such germplasm in the near future. For reasons outlined in the next section, this recommendation applies to relatives of livestock species both within and across species.

> **FAnGR RECOMMENDATION 1:** The CGIAR should work closely with the International Union for the Conservation of Nature (IUCN), FAO and other agencies to review the current status of conservation of wild relatives of livestock species and where necessary develop strategies for conservation of such species. Given the intrinsic human interest in most wild species of animals and birds it is unlikely that the CGIAR will need to play a major role in actual conservation.

The future value of wild populations and related species

Species related to domesticated species have received little or no attention from agricultural geneticists for the obvious reason that until the relatively recent advent of transgenic technologies, there was no mechanism of moving potentially useful genes across the species barrier. Transgenic technologies have been widely applied to successfully generate animals with functional and in some case useful genetic modifications. The majority of this work has been in the private sector and many of the details are not in the public domain. Transgenic technologies remain relative inefficient and expensive in livestock and consequently the focus of private sector work has been on very high value modifications, such as the generation of pharmaceutical products or precursors in milk, or modification of products such as milk for high value markets such as infant formula. There remain, however, largely untested social and ethical issues in production and marketing of transgenic livestock. These issues have so far deterred the introduction of transgenic livestock into commercial livestock production systems, and use of transgenic livestock has so far been restricted to highly controlled production systems for production of very high value products for pharmaceutical applications - even here no product has yet been licensed for commercial use.

Transgenic technologies for livestock continue to improve, and it would certainly be feasible even with today's technology to successfully produce transgenic animals in several of the major species and multiply them for dissemination into livestock production systems. Untested social responses notwithstanding, compelling argument can be made for the use of transgenic modification to improve the health and survival and perhaps even for improved productivity of livestock, particularly in the developing world. The possibility, for example, of enhancing resistance to specific diseases in a breed that is otherwise well adapted and moderately productive in a difficult production environment would have the advantage of generating useful genetic change without disrupting a well balanced genotype, as would inevitably result from cross-breeding. It would also avoid the negative effects of introducing new germplasm through crossbreeding or breed replacement, such as the lack of adaptation and disease resistance traits that come with many crossbreds or breed replacement. There is a possibility that a single or small number of genetic modifications would prove to have undesirable side effects after dissemination, but this probability would be much lower than with use of crossbreeding or breed substitution where tens of thousands of untested and largely undocumented genetic changes are introduced.

Box II.2: Disease resistance in wild relatives: trypanosome resistance

An example of genetically determined resistance in wild relatives that has been well demonstrated under controlled conditions relates to trypanosome infections in cattle. A small group of closely related West African short horn cattle breeds exhibit trypanotolerance, and can survive and continue to grow and produce in the presence of moderate (but not high) levels of trypanosome infection. Most other breeds of cattle will die if not treated after infection. In contrast, Cape buffalo and Eland, both very close evolutionary relatives of cattle, exhibit complete resistance to trypanosome infection. Both species develop and then control parasitaemia following infection, but show no clinical signs of disease and completely and rapidly eliminate the parasite after the initial parasitaemia develops. Phylogeny indicates that within the bovidae lineage Eland and cattle diverged after Cape buffalo. Physiological evidence indicates that Cape buffalo and Eland probably share the same relatively simple primary mechanism of resistance. Although the mechanism of genetic control of the physiological mechanism of resistance is unknown, there seems a reasonable chance that a relatively simple mechanism is involved and that if discovered a genetic modification could be introduced into cattle, sheep and goats to induce higher levels of trypanosome resistance.

Although improved efficiency of transgenic technologies will certainly aid the future application of transgenic livestock, the principal limitation today is not the technology but is the limited number of plausibly useful modifications that are available. Part of the problem is that the leading researchers in genetic modification are focussing their ideas and efforts on high value products for developed world markets rather than genetic modification of livestock to improve livelihoods in the developing world. Another problem is that the low level of understanding of mammalian gene function currently yields a limited supply of candidates for useful genetic modification. Wild relatives of livestock species are a possible future source of potentially useful genetic modifications. Many wild relatives of domestic livestock species undoubtedly possess potentially useful characteristics not present in livestock. Most notably, many wild species almost certainly possess high levels or complete resistance to diseases that afflict livestock. Remarkably little research has been undertaken to clearly demonstrate such genetic differences between livestock and their wild relatives, but it is clear from field observations that this must be the case. A reasonably well-documented example is provided on disease resistance in wild relatives (see text box II.2).

Genes controlling useful traits in wild relatives would make attractive candidates for transgenic modification of domestic species as they have high likelihood of working well in the genetic background of the livestock species given the overall high degree of genetic similarity between the livestock species and its wild relative. The tools of modern genomic science, such as high throughput gene and protein expression profiling, in process of development for several livestock species will provide opportunities for gene discovery in wild relatives of several livestock species; most notably those of cattle, sheep, pigs and chickens. In consequence, wild relatives of livestock species have become potentially powerful resources for generating useful information on genetic control of useful characteristics that can be applied in improvement of livestock, either through conventional genetic improvement or development of novel means such as new therapeutics, vaccines and nutritional interventions. Wild relatives can potentially also supply new variation for use in livestock species through genetic modification. Similarly, many wild animal species have become tractable models of mammalian processes that are of potential relevance to human medicine. Consequently, there are opportunities for external funding of research into gene discovery in wild relatives of livestock from sources not traditionally or widely accessed by CGIAR institutes (or indeed by other livestock research institutes globally), such as national science and medical research agencies[18].

An active program for genetic modification of livestock would require a major commitment of time and resources and could only be executed by the CGIAR in close collaboration with, at very least, centres of expertise in animal genomics, reproduction and gene transformation. It would not be sensible to embark on such research and development unless a clear route to market can be identified at outset, and there would need to be a concomitant program preparing the policy and social environment for acceptance of genetic modification. It is possible that the CGIAR might provide the role of a facilitator, rather than research provider, during early stages of such research, taking leadership to ensure that relevant genetic modifications are identified and routes to market and policy and social issues adequately addressed. The CGIAR would need to consider carefully its level of involvement in laboratory-based research. Several CGIAR institutes and closely allied ventures - such as Biosciences East and Central Africa (BECA) - have laboratory facilities capable of delivering

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[18] To illustrate the scale of possible funding from non-traditional sources, the National Institutes of Health (NIH) of the USA, has an annual research budget of $28.5 billion.

significant contributions. An investment in scientific expertise at levels sufficient to take leadership would also be required.

The ongoing flux in social attitudes towards genetic modification, coupled with the uncertainty about when useful genetic modifications will be identified and forthcoming, and taking into account other priorities for CGIAR action, argues that that CGIAR should not initiate substantial activities in the development of social and policy frameworks for genetic modification of livestock until routes to useful genetic modification are identified. In the interim, the CGIAR should maintain a watching brief on international developments in social and policy frameworks for genetic modification and be prepared to become involved if it appears that international developments might restrict opportunities for genetic modification to be applied for the improvement of livelihoods of the poor.

> **FAnGR RECOMMENDATION 2:** The CGIAR develop an international think tank involving world leaders in genetic modification of animals and birds to identify and assess genetic modifications that would improve livelihoods of the poor. A watching brief on genetic modifications being undertaken globally should be maintained. Where useful genetic modifications are identified a coherent strategy for development, testing and delivery of such modifications, including social and policy frameworks should be established and work initiated.
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> **FAnGR RECOMMENDATION 3:** The CGIAR develop international awareness among the research community, and facilitate development of, and where appropriate become involved in research into, genetic control of adaptation to physical and disease environments of species related to livestock species. Emphasis should be given to simultaneous development of capacity for useful research among NARS collaborators, in particular looking for opportunities to develop collaborative research through BECA, Nairobi.

Technical considerations in conservation of FAnGR

In vitro conservation programs

In marked contrast to the situation in plants, a number of biological and technical factors have discouraged the widespread establishment of *in vitro* germplasm banks for livestock. The contrasts between animals and plants for some of the key factors are listed in Table II.2. Most notably, *in vitro* preservation of viable germplasm in animals always requires storage in liquid nitrogen and technical efficiency is much higher for gametes rather than embryos. This results in high costs to prepare samples for storage and high costs of storage compared to plants. The general preference for storage of gametes rather than embryos, because of the low technical efficiency of collection and regeneration of embryos, also means that several generations (i.e. 3 to 25 years) of crossbreeding are required to re-establish a relatively pure line if the purebred live animals no longer exist. It is also expensive to evaluate animals for performance traits and very expensive and time consuming to evaluate them for adaptation and disease resistance traits. There are national and international veterinary regulations and laws that regulate the movement of *in vitro* conserved animal germplasm. In general, unless a germplasm bank can certify that samples were collected in approved, disease free facilities from disease free animals, then those samples are unlikely to be able to be used in most countries. The storage of samples collected in an unapproved manner in the same facility as sample collected in an approved manner could cause samples to lose their approved disease free status. An excellent summary of the technical and legal issues in *in vitro* conservation of livestock germplasm is provided by ERFP (2003).

In the early 1980s, Prof Charles Smith, prompted by discussion with FAO staff, developed an economic analysis that concluded that while the probability of use of a given *in vitro* conserved FAnGR was relatively low, the potential benefits from such use were very high and the costs of *in vitro* conservation were in comparison "trivial" (Smith, 1984a,b). Nevertheless the consensus in the international community by the early 1990s was that conservation of livestock should follow the priorities set by the Convention on Biological Diversity (CBD); namely that conservation should ideally be *in situ*, with *ex situ* conservation being less desirable and *in vitro* conservation being used only in emergency situations (FAO, 1998). The FAO Secondary Guidelines for management of small populations at risk (FAO, 1998) did provide substantial information on the technical and legal requirements for establishment and maintenance of cryopreservation gene banks for livestock germplasm, but subsequent expert reviews have focused on *in vivo* conservation (e.g. Oldenbroek, 1999).

There does not appear to have been any attempt by the international community to determine whether risks to FAnGR constitute an emergency warranting establishment of *in vitro* conservation programs and, if so, who should undertake that conservation and how they should be managed to promote maximum value of the resource and to deal with sovereignty and ownership issues. The assumption seems to have been that countries would manage their own genetic resources. Given the substantially greater technical difficulty of establishing and maintaining an *in vitro* conservation program for animal germplasm compared to plants, it is paradoxical that developing countries should be assumed to be able to operate their own animal germplasm conservation programs as needed, while large international efforts ensure conservation of plant germplasm. In even greater contrast, several European countries, the USA and Japan while showing no apparent interest *in vitro* conservation of FAnGR in the developing world, have established their own *in vitro* preservation programs. Rather than being a primary means of conservation, these *in vitro* programs mostly supply a back up to live animal conservation or simply store reserves of germplasm from outstanding individuals or lineages for possible future research or use.

The current review has earlier argued that the balance of evidence indicates that for the purposes of setting CGIAR strategy, FAnGR in the developing world should be considered to be in crisis. It is clearly an urgent priority that the international community review the needs for national and international programs for *in vitro* conservation of livestock germplasm and develop programs to ensure appropriate conservation is effected. Spurred by rising numbers of requests for assistance in establishing *in vitro* conservation programs, the CGIAR and FAO are planning an expert consultation in 2005 to review the needs for and technical issues supporting *in vitro* conservation of FAnGR. Given the current lack of awareness of all but one or two national and international development agencies, the CGIAR will need to play a central role supporting the debate about *in vitro* conservation and ensuring that appropriate international action is taken. It is not clear at this stage whether it would be sensible for the CGIAR to take a direct role by establishing and operating *in vitro* conservation facilities.

The CGIAR currently has no such facilities and no expertise in this area, but would be well placed to develop such expertise and would have several advantages as an independent agency when holding germplasm for many countries given the poorly developed policy environment. A move to establish such facilities would obviously involve a substantial and long-term commitment of resources. Cost and security considerations would drive location of such a germplasm bank or banks. A key factor in choosing a location is that even a short interruption of supply of liquid nitrogen can lead to complete loss of the accessions in an *in vitro* germplasm bank. Costs of liquid nitrogen vary nearly ten-fold between countries, and other costs also vary very substantially. Such factors argue for establishment of international germplasm banks in low cost developed countries. In contrast, political forces may favour locations in the developing world and strict veterinary health regulations of many developed countries may make movement of germplasm into and out of such a germplasm bank problematic. These will be tricky issues to resolve and if the CGIAR was to take on a direct role in management of FAnGR *in vitro* conservation facilities it would clearly require broad international support, both politically and financially. While the political and to lesser extent the financial costs of involvement in the process of developing an international effort in this area are daunting, the CGIAR also faces major risks in taking no action. Apart from moral obligations given its international role, if a substantial proportion of the world's FAnGR are lost through inaction, the CGIAR will face a major loss of credibility, being the best placed of all international agencies, along with FAO, to recognise and react to the needs for conservation before substantial resources are lost.

> **FAnGR RECOMMENDATION 4:** The CGIAR should take urgent action with FAO and other agencies to review the needs for and structure of a global program for *in vitro* conservation of FAnGR. As a matter of urgency the CGIAR should develop a clear strategy for its own actions, either directly in establishing and managing or in facilitating and providing oversight to the establishment and management of an *in vitro* genebank or banks. The strategy should include relevant action to resolve issues in access and benefit sharing and other regulatory and policy issues affecting establishment and management of the germplasm bank(s).

***In situ* and *ex situ* conservation**

The majority of development agencies, FAO and the CGIAR institutes have either directly or tacitly endorsed the priority given to conservation of FAnGR *in situ*. FAO and other agencies have worked together to develop guidelines for management of small populations at risk (e.g. FAO, 1998; Oldenbroek, 1999), and CGIAR staff have made contributions to that process. It is only recently however that the CGIAR and other agencies have become directly involved in establishment of *in situ* conservation programs. It is generally (though not universally) accepted that poor farmers and those who advise them have a primary obligation to improve the livelihoods of their families and community, and as such have no obligation to maintain genetic diversity for future use by others. Thus *in situ* conservation is sustainable only to the extent that the FAnGR being conserved also provide the best available livelihood strategy to the livestock keepers. Given the constant evolution of agricultural production and marketing systems throughout the developing world, it follows that *in situ* conservation will be successful only where the livestock involved maintain competitiveness as a livelihood strategy in the present and the future. That implies that *in situ* conservation includes genetic improvement of the FAnGR to ensure its competitiveness as a future livelihood option.

The overarching obligation of the CGIAR and other agencies of change is to provide options for livelihood improvement to the poor. Those involved in promoting and enabling *in situ* conservation need, therefore, to be clear that conservation of an existing FAnGR is the best livelihood strategy for the livestock keepers. This assumes that there is good information on whether alternative FAnGR would provide better livelihood options for a given community. It also requires that access to superior FAnGR can be achieved. There is certainly a danger that support for *in situ* conservation may turn out to be based more on a lack of information on which FAnGR would provide better livelihood options, rather than being based on informed decisions demonstrating that *in situ* conservation is the best livelihood strategy.

The uncertainties more than justify the involvement of the CGIAR in R&D relating to establishment and maintenance of *in situ* conservation programs and argue for attention being given in identifying viable models for *ex situ* conservation. The above discussion also illustrates that the issues of conservation, characterisation and genetic improvement are neither logically nor safely separated from each other if the CGIAR (and other agencies) is to fulfil its mandate and its moral obligations to the poor.

Given the uncertainties about *in situ* conservation, it would be prudent of the CGIAR and other agencies to give serious consideration to other options of conservation, including *ex situ* (live animal) conservation. *Ex situ* conservation appears to have been largely dismissed as a viable option for conservation of developing world FAnGR, with descriptions of sustainable *ex situ* conservation programs applying almost exclusively to developed world systems (see Alderson, 1990; Anonymous, 1995). At first sight, *ex situ* does not seem a particularly attractive option for many developing world settings. *Ex situ* conservation requires access to substantial physical resources, either through dedicated farms or reserves, often with substantial financial support to maintain populations. In the developed world *ex situ* conservation has been effected through state run farms, but more widespread have been the maintenance of populations in dispersed networks of small populations held by rare breeds enthusiasts.

Concerns in the developing world relate to the sustainable maintenance of *ex situ* conservation programs when managed by the state and the absence of sufficient numbers of rare breeds enthusiasts with the resources to maintain rare breeds for their own interest. Nevertheless, with substantial unanswered questions about the degree to which *in situ* conservation will prove a viable conservation strategy, it would be prudent to develop sustainable options for *ex situ* conservation. A cursory review of the raw data submitted by countries as part of the current State of the World (SoW) review of FAnGR organised by FAO, indicates that a substantial proportion of developing world countries are operating *ex situ* conservation programs. In most cases, however, the information supplied in the SoW reports is insufficient to judge what proportion of such programs are technically secure in terms of population size, representative sampling of the original population, rates of inbreeding, selection program, and other aspects of population management, or whether they are financially and socially secure. This argues the need for more detailed information on how well existing programs are being managed and what assistance countries most need to operate effective *ex situ* conservation programs.

> **FAnGR RECOMMENDATION 5:** The CGIAR should develop a strategy for conservation of FAnGR that recognises that characterisation, conservation and

utilisation of FAnGR are neither logically nor safely separated from each other. The CGIAR strategy should therefore encompass all aspects of R&D required to ensure livestock keepers have access to the FAnGR that best meet their livelihoods. That strategy will encompass, the gathering and dissemination of information on characterisation and status of FAnGR, the development of strategies for effective and sustainable conservation of FAnGR, and the development of strategies for utilisation of FAnGR, both through genetic improvement of FAnGR and understanding of genetic mechanisms of adaptation, disease resistance and productivity and product quality. The strategy will include definition of the CGIAR role in capacity development and in development of regulatory and policy frameworks that will promote sustainable conservation and utilisation of FAnGR.

FAnGR RECOMMENDATION 6: The CGIAR should continue to play a leadership role in research into the establishment of sustainable *in situ* conservation programs, being mindful in such research of its moral obligation to provide to livestock keepers options that most enhance their livelihoods. A component of the research should be to determine the future viability of *in situ* conservation as a primary method of conservation of FAnGR

FAnGR RECOMMENDATION 7: The CGIAR should work closely with FAO to review the need to support developing countries to establish and maintain *ex situ* conservation programs, and from that review develop a strategy for activities related to *ex situ* conservation of FAnGR that meets the needs of developing countries.

Characterisation and status of FAnGR

Genetic improvement at the farm level might involve breed replacement, crossbreeding or within breed selection. Genetic improvement within breeds, while relatively slow, is a steady cumulative process that can provide high benefit to cost ratios. These high returns are however generated in the long- rather than the short term. It is therefore important to ensure that, among other factors the breed being improved is the best breed available and will not be replaced by a breed returning better livelihoods in the short to medium term. Thus the first choice in genetic improvement in a given production system is whether the existing breed provides the best livelihood option[19] to the farmers involved, or whether they benefit by use of another breed or establishment of a crossbreeding system. Well informed choices about breed substitution and crossbreeding require detailed information about the production, reproduction, adaptation and disease resistance characteristics of all breeds of livestock along with information on breed status and availability.

It was noted in Table II.1 that characterisation of FAnGR is generally very much more expensive than the characterisation of PGR. Reproduction, adaptation, survival and disease resistance are all particularly difficult and expensive to record. Obtaining accurate information on FAnGR faces a double difficulty that resources and infrastructure for accurate characterisation are scarce, and the characteristics that are most difficult to record

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[19] Livelihood is used here in its broadest sense, including the balance of income, securing of assets, asset accumulation, insurance and social value.

are often those of greatest value in the low input systems typical of the developing world. The consequence is that the majority of FAnGR have not been characterised in sufficient detail to allow informed choices about the most suitable breed, or crossbreeding system, for most low input farming systems. Indeed, there is essentially no reliable data on the characteristics of a substantial proportion of developing world FAnGR. This contrasts markedly with the situation in the developed world, where a high proportion of breeds of the major livestock species have been very well characterised, at least in terms of ability to generate profit in intensive production systems[20]. A compounding problem for developing world FAnGR is that the data on characterisation is often published in institutional reports, national or regional journals that are hard to access. A substantial proportion of the data published in international journals was published a long time ago and is not accessible through electronic bibliographic search. There is a need for much greater effort to characterise the FAnGR of the developing world and also to make the data that does exist more readily available.

In the absence of sufficient high quality information on characteristics of FAnGR in the developing world, molecular genetic markers can provide relatively rapid assays of genetic diversity. Such assays can provide evidence of relationships within and between breeds of livestock that have application in decision making in both conservation and utilisation (see Gibson and Bishop 2005, and Gibson et al., 2005)[21]. The CGIAR was one of the leaders in initiating projects to assay molecular genetic diversity of FAnGR and has developed some of the most extensive surveys of diversity of cattle, sheep, goats, yaks and camels of the developing world (e.g. Hanotte et al., 2002; Chenyambuga et al, 2005; Jianlin et al., 2005; Xuebin et al., 2005). The CGIAR has also played a lead role, independently and through collaboration with international experts, in developing frameworks for use of molecular diversity data in conservation and utilisation (Simianer et al. 2003; Reist-Marti et al., 2003; Freeman et al., 2005).

There remain many unanswered questions about how molecular and other data should optimally be combined for decision-making and to develop and disseminate user-friendly tools for decision making. A problem has also arisen following the failure of the original assumption that data on microsatellites, the markers of choice today[22], could be combined across studies. At the time that the CGIAR and many other groups independently, initiated their microsatellite-based genetic diversity studies, it was expected that data would one day

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[20] This contrast between developed and developing world in availability of information has undoubtedly contributed to the focus on use of developed world germplasm breed replacement or crossbreeding in the developing world. Advisors and development agencies seeking to improve farmer livelihoods review the information available when making their choices. When the information available is predominantly, sometimes exclusively that for developed world FAnGR, developing world FAnGR are not considered as an option. This can result in difficult to maintain, and sometimes unsustainable crossbreeding programs based on developed world germplasm with high production potential, when it might have been substantially better to utilise only moderately more productive but much better adapted germplasm from the developing world.

[21] Since both these papers are not yet published, the abstracts are provided as a footnote to the reference list.

[22] The potential use of other types of genetic marker is being explored by various groups. Most promising markers are single nucleotide polymorphisms (snp) and Diversity Array Technology (DArT) (Wenzl et al., 2004). Both technologies currently have their own limitations and both require further development before they would prove more cost effective and/or easier to apply than microsatellites. Meanwhile genetic diversity data continues to accumulate based mainly on microsatellites. As microsatellite data accumulates it will be harder for new marker technologies to compete as they likely have to genotype most of the samples already genotyped for microsatellites.

be combined across studies to provide a single meta-analysis of the diversity of the worlds breeds[23]. This has not proven possible. Statistical methods might be developed that will allow rescue of some of the information across studies, but such methods are as yet untested and it is clear that they will not yield the quality of information originally expected from analyses across studies. This difficulty argues that the CGIAR should extend the scope of its molecular diversity studies. The overarching goal should be to ensure that all the studies it engages in contribute to linking a high proportion of the developing world's FAnGR into a detailed global analysis. It is unfortunate in this regard that the two CGIAR institutes working on molecular characterisation of FAnGR (ILRI and ICARDA) have so far failed to agree a form of collaboration that will guarantee that their data will ultimately be able to be joined into a single analysis.

> **FAnGR RECOMMENDATION 8**: The CGIAR should review its strategy in molecular diversity assay with the goal of ensuring that a global analysis of the genetic diversity of the FAnGR of the world's major livestock species can be completed within the near future, recognising that such information will be required in decision making in both conservation and utilisation. The CGIAR should ensure that the work of its own institutes is fully harmonised and consistent with this goal. In order to fulfil this goal, the strategy should define the role of the CGIAR and its collaborators in ensuring that the databases, and statistical and decision making tools that will be required are developed and made available in user-friendly form.

FAnGR databases

While there are a number of websites that contain some information on developing world FAnGR, only two provide sufficient coverage to be useful in decision-making. FAO has developed and maintains the DAD-IS database (http://dad.fao.org/home.htm), while ILRI has developed and maintains the DAGRIS database (http://dagris.ilri.cgiar.org/dagris/).

DAD-IS is maintained as an information resource on conservation and management of FAnGR. In addition to extensive lists of guidelines and reports of intergovernmental processes related to FAnGR, it includes a database into which countries can enter their own data on breed characteristics and status that they choose to make available publicly. For a given country, each breed has a single entry providing production averages for a limited number of key traits. Typically, neither the environment in which production data was collected nor the source of the information is listed. FAO personnel can alert countries where they believe there are errors in the information, but it is up to the countries whether and how the information is corrected. The database provides a very useful starting place to identify which FAnGR exist in a given country and provides a snapshot of breed characteristics, with the limitation that breed lists remain incomplete for some countries. It can also be used to

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[23] In the 1990s, FAO constituted MoDAD (http://dad.fao.org/en/Home.htm; FAO, 1994a,b) in collaboration with the International Society of Animal Genetics (ISAG) and other international science groups to recommend sets of microsatellites and protocols for molecular genetic diversity assay of FAnGR. These recommendations are being revised in light of results obtained since the first MoDAD recommendations were published. CGIAR staff made contributions to the MoDAD process. The CGIAR work in molecular genetic diversity has received occasional criticism for not always using MoDAD panels. Such criticism is unfounded because CGIAR work preceded publication of MoDAD guidelines, necessitating that the CGIAR team make their own choices on microsatellite panels. The MoDAD guidelines have since been shown to have several flaws (now being rectified) that have led to rather little consistency across research groups in the sets of markers used.

identify in which countries a given FAnGR exists, with the limitation that many breeds have different names in different countries and the list of synonyms is not always complete for each entry. The low level of information on physical and production environments and the limited amount and highly variable quality of the characterisation data mean that DAD-IS is not very suitable for identifying germplasm existing in one location that might prove useful in another.

DAGRIS is maintained by ILRI as a database into which data is transcribed and edited from a wide range of publications, ranging from institute and ministry reports, and national, regional and international journals. Each breed in each country also has descriptions of breed origin, production system, geographical distribution and status. These descriptions are either prepared by ILRI staff or commissioned from experts familiar with the breed. Users can search the database at a variety of levels. Within a breed, users can access summaries of performance data taken from all the publications that have been entered, and from each data entry, the user can go to the abstract of the paper from which the data was taken. At present the database includes a relatively comprehensive collation of data for African cattle, and substantial collations for sheep and goats, also mostly in Africa. A start is being made on chicken breeds. DAGRIS has provided a very major step forward in availability of existing information on FAnGR for the small number of species and limited geographical region it covers.

Expanding DAGRIS to meet the immediate needs to encompass all livestock species, or at least all major species, in all regions will be well beyond the capacity of the small team of people currently managing DAGRIS. Although very labour intensive, the current mode of operation has worked well for Africa because the ILRI staff have been able to draw on the comprehensive collection of publications on ruminant livestock production research in Africa held by the ILRI Addis Ababa library. Extension to other regions and species will require a new mode of operation. DAGRIS is also far from comprehensive in providing the range of information and functions that will be required for effective decision taking in utilisation and conservation of FAnGR. Examples that would enhance the value of DAGRIS include, *inter alia*, a facility to capture molecular genetic diversity data along with tools for users to analyse such data; a matching of breed distribution to GIS information to allow users to determine the environmental conditions under which the breed thrives; the ability to analyse data across experiments and specifically to be able to extract comparisons between breeds[24].

DAD-IS and DAGRIS have been developed so far quite independently of each other and in the past there have been tensions between the FAO and ILRI reflecting a lack of communication leading to misunderstanding of the different objectives of the two databases. These tensions have been resolved in recent years and it has been agreed that FAO and the CGIAR will collaborate closely in further generation of FAnGR databases. But at present no clear strategy exists for how that collaboration will be developed. While the CGIAR and FAO

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[24] At present DAGRIS summarises the data for a given breed experiment by experiment and the user has to read each abstract in turn to discover what other breeds were included in each trial in order to create their own summaries of comparisons between breeds. In the absence of comparative information, simply comparing averages of results for one breed against averages for other breeds, whilst better than having no information at all, can nevertheless be highly misleading because performance is highly dependant on both the environment in which the breed is tested and the exact definition of the traits recorded.

can be commended for their contributions to FAnGR databases to date, FAnGR databases urgently need to provide detailed information for a far greater coverage of species and regions. They also need to develop a greater range of data coverage and functionality. To move to the next step will require very substantial changes in modes of operation and may well dictate a change in database platforms. It will certainly require new funding. The range of tools and information required is well beyond the current capacity and expertise within the CGIAR and FAO combined and both parties will need to engage a wide range of new partners if the promise of FAnGR databases is to be fulfilled. At present both DAD-IS and DAGRIS are effectively electronically accessible encyclopaedias with useful but still very basic search engines. In developing the next generation databases, all parties should pay attention to harnessing the power of HTML to develop new architectures of information flow and broad participation in information provision.

> **FAnGR RECOMMENDATION 9**: The CGIAR needs urgently to make a substantial commitment to the development of a database for FAnGR that is comprehensive in terms of species, regions and information content, as well as providing to users a range of tools to analyse and interpret data and aid decision-making. In doing this, the CGIAR should work closely with FAO and the international community generally in both the design and the establishment and filling of the databases. Establishment and filling of the new database will build on the knowledge gained in developing the existing databases, but will almost certainly require new modes of operation and a more partnership-based approach on the part of the CGIAR.

Utilisation of FAnGR

It has been noted that FAnGR are in a constant state of change. Most livestock keepers of the developing world have a set of criteria that define good breeding stock and without any technical training or guidance select for the most improving males and females as parents of the next generation. Thus virtually all breeds of livestock are under constant selection for improved characteristics or for maintenance of an ideal. In addition, most livestock keepers are entrepreneurs. While attached in varying degrees to their traditional breeds, most farming communities will adopt alternative germplasm if they perceive benefits in doing so and have access to such germplasm. The patterns of livestock genetic diversity today (e.g. see Hanotte et al., 2002) reflect a long history of movement of livestock germplasm and either direct adoption by local farmers or foundation of a new stock through crossbreeding with local germplasm.

The ability of poor farmers to effect genetic improvement notwithstanding, several factors argue for the need to increase the capacity of the developing world to undertake genetic improvement: 1) There is now a substantial body of theory and practice in genetic improvement of livestock that has allowed the developed world to effect very rapid and large changes in the germplasm used in most production systems. This theory and practice has not so far been effectively transferred to most of the developing world. 2) Farming systems globally are changing at unprecedented rates. In the developed world, genetic improvement of livestock has contributed about half of the total gains in productivity and efficiency, the other half coming from improved feeding and husbandry (Smith, 1985). The indigenous germplasm of developing world farming systems will need to be able to respond effectively to changing production systems or will be lost to other more productive germplasm. 3)

Modern communications and transportation have led to massive increases in movement of livestock germplasm in the past 50 years or so. Developing world farmers and the advisors and agencies who serve them need appropriate tools to deal with the information on what genetic resources are available to them and to be able to assess the appropriate role of germplasm that is made available to them. As discussed earlier in this report, without appropriate assessment, new germplasm can rapidly overwhelm an indigenous germplasm before the suitability or lack of suitability of the new germplasm is known.

There is an extensive literature on the theory of genetic improvement of livestock and a much smaller literature that attempts to provide working guides to livestock genetic improvement. All of this literature is designed for the developed world and none provides a useful guide to application in developing world situations. Moreover, none of the existing literature is considered suitable to guide people not already expert in the subject through the process of design and operation of sustainable improvement programs. Recognising the need to provide tools to assist countries design sustainable genetic improvement programs, in the 1990's FAO, and ILRI with the Swedish Livestock University (SLU), independently initiated work to develop training materials designed to improve the capacity of developing countries to operate sustainable genetic improvement. The FAO process lead to an international workshop in 1999 (ICAR, 1999) at which delegates provided input materials and discussed content of guidelines for livestock genetic improvement. These materials were further developed by a small team of consultants working with FAO staff, but as yet no guidelines have resulted and FAO is currently reviewing its strategy for developing these materials. The ILRI-SLU collaboration aimed to provide training materials for trainers (mainly University teachers) in livestock genetics and management of livestock genetics resources, including genetic improvement programs. ILRI and SLU have run a series of training workshops and courses in Africa that are now expanding into Asia. The first version of the training materials has been released on CD-ROM (ILRI–SLU, 2003).

The ILRI-SLU courses and materials have made a significant contribution to raising capacity of trainers of trainers. Nevertheless, the need for training materials, guidelines and templates and for active training and capacity development goes well beyond what is currently available. At its most recent meeting in November 2004, the CGRFA (Commission on Genetic Resources for Food and Agriculture) made the following recommendation:

"The Commission emphasized the need for breed development in low- to medium-input production systems, and requested FAO, in collaboration with relevant partners, to finalize the development of the decision-support tools, to assist in the formulation of breeding programmes. The Commission stressed the importance of further implementing proven classical breeding programmes in extensive production systems."

Since FAO is currently reviewing its strategy on sustainable improvement of FAnGR, it is a suitable time for the CGIAR to work out a joint strategy with FAO to meet the needs identified by the CGRFA.

> **FAnGR RECOMMENDATION 10:** The CGIAR should increase its level of investment in sustainable genetic improvement of FAnGR, including methods of decision-making in breed choice and crossbreeding as well as selection within breeds and the role of reproduction and genetic/genomic technologies. A

> particular focus should be given to the integration of *in situ* conservation and sustainable utilisation and improvement of FAnGR. Emphasis should be given to capacity development in sustainable genetic improvement and the CGIAR should integrate its programs with FAO activities, preferably through the operation of a joint program of activities.

Policy and regulatory frameworks for FAnGR

No international agreements exist for regulations or policy that specifically relates to the management, sovereignty, ownership and benefit sharing for FAnGR. Based on personal communications from FAO and ILRI staff, there are very few countries globally that have policy frameworks explicitly for managing FAnGR. At the international level, the only binding framework for FAnGR is the Convention on Biological Diversity (CBD). The PGR community agreed that CBD was not a suitable framework for management of agricultural biodiversity, and entered into lengthy negotiations that have recently culminated in the ratification of the Treaty on Plant Genetic Resources. There has been a steadily growing debate on the need for a legal framework to deal with sovereignty and benefit sharing for FAnGR. The SADC countries have been particularly active in regional debate. A recent series of workshops in SADC countries, assisted by FAO and other development agencies (including CGIAR) and NGOs, discussed the issues and options for a legal framework to manage FAnGR, without reaching a firm conclusion but identifying that the issues were complex. Several NGOs, with increasing support of developing countries, have called for an international agreement on FAnGR at recent international fora. A workshop of NGOs and community organisations developed the Karen Commitment[25] in October 2003 (Koehler-Rollefson, 2004), and various calls for an agreement were made that the 2004 meeting of the CGRFA (The FAO Commission on Genetic Resources for Food and Agriculture; see FAO 2004). The 2004 CGRFA meeting did not vote in favour of developing an international agreement at this time, feeling that it was appropriate to await the First Report on the State of the World's (SoW) Animal Genetic Resources, due to be discussed by the CGRFA in 2006. The CGRFA has meanwhile given FAO the mandate to coordinate the development of international policy and regulatory frameworks for all aspects of agrobiodiversity. It seems quite likely that in 2006 the CGRFA will formally request that FAO should start developing a policy and legal framework for FAnGR. The international R&D community therefore has about two years of lead time to ensure that adequate information is available for an informed debate. While the CGIAR has made some useful contributions to the debate on policy and regulatory frameworks, such contributions form a very minor part of current activities and if continued at current levels[26] will not make a substantive contribution to the forthcoming international debate.

The CGIAR and FAO have worked very closely over the past 20 years or so in providing information and research, and facilitating the international debate on policy for management of PGR. Given the relatively low level of investment in FAnGR, it will be even more

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[25] The Karen Commitment calls upon the international community to reach agreement on a number of issues relating to sovereignty, intellectual property and benefit sharing for use of FAnGR, including provision for the rights of traditional livestock keepers

[26] At present there is a small initiative for livestock that has been added to the Genetic Resources Policy Initiative (GRPI - see Table II.4), as a collaboration between IPGRI and ILRI. The UNDP GEF and the proposed UNEP GEF projects will likely involve activities related to policy and regulatory frameworks, but these will likely be on rather specific aspects of conservation and focused on national or local regional applications.

important that FAO and the CGIAR, along with many other agencies, work very closely to focus and coordinate their activities on policy and regulatory frameworks for FAnGR, both at the international and national levels. There are increasingly calls for policy frameworks for other aspects of agrobiodiversity (including forestry, and fisheries) and the CGIAR will likely have a substantial role to play in such policy development. The requirement for very close collaboration with FAO, the opportunity and need to develop coherent policies across different aspects of agrobiodiversity, and the opportunity for synergy in expertise and learning across the different debates argues strongly that the CGIAR should establish a single focus for its activities in regulatory and policy frameworks for agrobiodiversity. This focus should be a unit based in Rome.

> **FAnGR RECOMMENDATION 11**: Anticipating the growing debate about the regulatory and policy frameworks for management of agrobiodiversity nationally and internationally, the CGIAR should develop a single focus for CGIAR research activities in regulatory and policy frameworks across the spectrum of agrobiodiversity (including plants, livestock, fish, trees and others). The focus should be a unit based in Rome to promote the extremely close collaboration with FAO that will be required and to draw on the expertise in dealing with the political, legal and human issues that has been developed during the development of regulatory and policy frameworks for PGR. The unit will be expected to work closely with other CGIAR institutes to provide the research and information inputs that will be required by FAO and the international community.

Current levels of CGIAR investment in FAnGR

Table 3 compares the nature and extent of global (i.e. of all parties, including CGIAR) activities in PGR and FAnGR in very broad terms. The nature of the activities differs markedly between PGR and FAnGR, reflecting to large degree the differences in biology and application of PGR versus FAnGR that were summarised in Table II.2. But there are also substantial differences that reflect levels of global commitment and/or awareness of issues in FAnGR and the fact that development of international debate and action on management of FAnGR is well behind that for plants. The level of the investment in FAnGR activities by the global community, and by the CGIAR is a small fraction of that for plants. This is exemplified in the last two rows of Table II.3, which show that CGIAR investment allocated to PGR versus FAnGR is in the ratio of 9:1 or possibly greater[27].

Table II.4 summarises the activities and investments of CGIAR institutes at the project level, based on information supplied directly by the institutes for this report. At present, three institutes, ICARDA, ILRI and IPGRI, and one system-wide program, SGRP (the Systemwide Genetic Resources Program), have activities on FAnGR. A total of 12.27 FTE of research leadership positions are involved in characterisation, conservation and utilisation of FAnGR, with 4.95 FTE supported by institute core funds and 7.32 FTE on project funds. An additional 30.69 FTE of support staff (including graduate students) are involved, with 14.29 FTE on core funds and 16.4 FTE on project funds. The total annual budget for activities related to FAnGR

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[27] Relative investment is indicated by defining the approximate number of research leadership positions (postdoctoral fellows and above) calculated in "full time equivalents" or FTE. The author was not able to obtain accurate estimates of the number of FTE involved in utilisation of PGR. See Table II.3 for the assumptions that were made.

is approximately $3.02 million, with approximately $0.65 million from core funds and $2.38 million from project funds. The distribution in expenditure between institutes is: ILRI, 93%; IPGRI and SGRP, 5%; and ICARDA, 2%.

As discussed earlier in the report, it is difficult to separate activities in characterisation, conservation and utilisation as these activities should be, and very often are interrelated and integrated within the same project. As examples, the ILRI projects on identification of genetic factors controlling disease resistance involve characterisation of FAnGR, with a view to, and including elements of utilising these mechanisms of disease resistance. Elements of this work will also contribute to conservation projects. Similarly, the projects on *in situ* valuation and conservation include components of characterisation, conservation and utilisation. Nevertheless, to obtain a very crude estimate of relative division of investment, it has been assumed that ILRI projects 11 to 15 in Table II.4 are mostly aimed at utilisation, whereas other CGIAR projects listed in Table II.4 are more oriented towards characterisation and conservation (including policy development). This leads to a rough partition between characterisation and conservation versus utilisation of approximately 5.8 vs 6.7 scientific FTE, 12.7 vs 18.0 support FTE and $2.10 million vs $1.20 million total funding.

There is an apparent disparity between FTE (higher for utilisation) and funding (higher for characterisation and conservation). This disparity is due to a substantial proportion of the project funding for characterisation and conservation being used to subcontract collaborators, whereas most of the funding for utilisation is spent within the CGIAR institutes. The disparity appears to reflect the sources of external funding obtained rather than fundamental differences in ways of doing business. Thus ILRI project 13 (see Table II.4) involves a consortium of collaborators, with approximately $1.3 million per annum going directly to the collaborators from the funding agency and not appearing in the ILRI budget totals. Similarly, the external funding of $509,000 for ILRI project 5 (see Table II.4) relates to UNDP GEF (Global Environment Facility) funding to ILRI to be the executing agency for GEF in the UNDP GEF and the African Development Bank (AfDB) funded project on conservation of West African trypanotolerant livestock, due to be initiated in July 2005. The annual funding from GEF to ILRI will rise to over $1million from 2006. The AfDB contribution of approximately $1.42 million per annum is awarded directly to the four countries involved. CGIAR staff played central roles in designing and obtaining funding for both of these projects, illustrating the very substantial impact of CGIAR investment on activities and funding outside the CGIAR.

The needs for future CGIAR activities in FAnGR identified throughout this report focus more on filling particular urgent needs rather than obtaining a better balance of activities across the broad spectrum of characterisation, conservation and utilisation. Examples, among others discussed in more detail elsewhere in this report, include: a substantial commitment and clear role in development of policy and regulatory frameworks for management of FAnGR; a detailed assessment and possible active role in *in vitro* conservation of FAnGR; a clear and focused program on sustainable methods of genetic improvement of FAnGR.

Strategies and activities of other agencies in FAnGR

In preparing this report, twenty seven donor and development agencies were contacted requesting information on their strategy and activities relating to FAnGR in the developing world. Despite follow-up requests, only 7 agencies responded. The lack of response in most cases almost certainly reflects the lack of an agency strategy or significant level of activities in FAnGR. Known exceptions are CIRAD, France and DANIDA, Denmark.

Table II.5 summarises information on donor and agency strategies and activities, based on responses to request for information, or on personal knowledge and/or information on their web site. Few agencies have any formal policy on FAnGR. Based on personal experience, in some cases this lack of strategy likely reflects an active belief that FAnGR rank low on global priorities; but in most cases it seems more related to a lack of awareness. A high proportion of the stated expenditure of agencies in FAnGR is channelled through CGIAR institutes. High proportions of activities are in collaboration with, or are directly within, CGIAR institutes. Thus, with the only substantial exceptions being FAO, CIRAD and AfDB, the majority of funding and activities listed in Table II.5 are included wholly or in large part within the Table II.4 of CGIAR activities. Approximately 8 FTE are invested by agencies beyond their contributions to CGIAR FTE. Undoubtedly there are other FTE contributions that have not been captured, but it is unlikely that there would be large blocks of FTE elsewhere. This accounting does not attempt to estimate the FTE invested in developing world FAnGR by developed and developing world academic and national research institutions. But based on personal experience, such contributions, while not insignificant, are scattered, involving the efforts and interests of individuals, and largely uncoordinated. It is clear that the level of awareness of, commitment to, and activities in, FAnGR outside the CGIAR is a small fraction of that for PGR. In comparison to PGR, the CGIAR, and certainly the CGIAR and FAO combined, appear to account for a much higher proportion of global activities than is the case with PGR. The conclusion must be that the decisions that the CGIAR takes on its involvement in FAnGR will have a greater impact on global activities and capacity to manage the worlds FAnGR than would equivalent decisions for PGR.

Current capacity of developing countries to manage their FAnGR

The majority of information on current capacity of developing countries to manage and develop FAnGR is scattered and mostly anecdotal. The DAD-IS database contains information on whether a conservation or utilisation program exists for a given breed. But in many cases the information is missing and when it does exist there is usually no information on the nature of the conservation or utilisation program. In the current SoW for FAnGR, countries are asked to provide details on the current status and plans for management of their FAnGR. Although a high proportion of countries have now returned their reports, no analysis of the data on management programs for FAnGR has yet been undertaken. A preliminary analysis of the needs for technologies in management of FAnGR, as identified by countries in their SoW reports, has been presented (Cardelino et al., 2003), as follows:

"From country reports analyzed to date by FAO, it is concluded that AI (artificial insemination) is the most common biotechnology used by developing countries and needs are expressed for training and expansion. Often AI is introduced without proper planning and is seen as a potential threat to the conservation of local breeds. Although ET (embryo transfer) use is mentioned and the desire for its introduction or expansion expressed, no clear objectives for this technique are mentioned. All countries have expressed a wish for the introduction and development of molecular techniques, often as a complement to phenotypic breed characterization. Cryoconservation was identified as a priority by all countries and gene banks were recommended, but at the same time funding remains a major constraint. When GMOs are mentioned it is mainly to express the lack of proper regulations and guidelines for their

eventual production, use and exchange. It is, however, not clear in all cases whether the technologies used are a sensible part of an overall genetic improvement strategy."

FAO kindly supplied the author of this report with original copies of 160 country reports submitted for the first SoW on FAnGR. The volume of material was too overwhelming for a detailed review[28]. The following observations are therefore based on reading of a small subset of reports from developing countries in Africa and Asia.

- Most country reports indicate a relatively high level of awareness about the existence and need for management of their FAnGR.
- Many countries, including some of the poorest countries, state that some form of management program (either conservation or genetic improvement) is in place for a substantial proportion of the indigenous FAnGR of that country. But there are a substantial proportion of countries, not always the most poor, that have no active management plans.
- In few cases is there sufficient detail to determine the design of the management programs, although in most cases it can be inferred that management of FAnGR does not involve *in vitro* conservation.
- Where information is provided about the management programs, there is generally insufficient information to determine whether management programs are appropriately designed and potentially sustainable.
- In a proportion of cases there is sufficient information to predict that if conservation of the breed relies solely on the stated management program, then conservation will unlikely be sustainable in the long run.
- Institutional structures and policies for management of FAnGR seem generally to be weak.
- Most countries identify needs for training of human resources to better manage FAnGR.
- Most countries identify the need to develop or improve their FAnGR conservation and improvement programs, with a substantial proportion identifying a need for *in vitro* conservation.
- While country reports often provide insufficient detail to judge accurately the state and sustainability of individual activities in management of FAnGR, the totality of information provided generally provides a strong guide to the extend of commitment, human, physical and economic resources devoted to, or available for, FAnGR management. As such the reports will be invaluable in guiding research and development agencies and NGOs on the level of support that different countries will likely require. They will also allow rational selection of countries in which to test interventions at various levels of human and infrastructure development in relation to management of FAnGR.

Overall, the information emerging from the SoW tends to confirm the personal reports of those working in livestock development in the developing world. That is, examples of successful conservation and improvement of FAnGR notwithstanding, in most cases the management of FAnGR remains poorly understood, poorly resourced and poorly supported by policy. In

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[28] Most country reports present 50 to 120 pages of information on the state of FAnGR and their management in that country.

contrast, awareness of the importance of FAnGR and of the need to develop sustainable management programs and appropriate policy is now widespread. There is great demand for and increasing commitment to sustainable management of FAnGR in developing countries.

Future investment and organisation of CGIAR activities in FAnGR

The conclusion of this report is that although the total investment of the CGIAR in activities related to management FAnGR is relatively small, it nevertheless accounts for a substantial proportion of global activity on FAnGR of the developing world. The CGIAR is undoubtedly an important leader in many areas of activity. The CGIAR is also better positioned than any other organisation to facilitate a global coordination of activities of other research providers so that the relatively modest global investments in FAnGR of the developing world are put to best use to achieve significant improvements in management and increased security of the world's FAnGR. The conclusion is that, if managed appropriately, an increased investment by the CGIAR in research related to management of FAnGR has potential to have a disproportionately large impact globally.

A cursory analysis of CGIAR investments reveals the anomaly that while the importance of livestock to the developing world agriculture and to the livelihoods of the poor has been steadily increasing since the early 1980's, the CGIAR investments in livestock have fallen dramatically. It is estimated that livestock products will soon account for 30% of agricultural output of the developing world, and that livestock provide especially favourable opportunities for agriculturally-based routes out of poverty. In 1983 the CGIAR budget for livestock research was approx 14.5% of its total budget (i.e. the budget for ILRAD and ILCA, assuming minimal livestock activities elsewhere in the CGIAR; see CGIAR, 1984). By 2004 the proportion of the CGIAR budget spent on livestock research was only about 9%. Whatever other factors lie behind this contradiction in trends in CGIAR investment versus trends in global importance of livestock, it is clear that the low levels of investment in livestock generally leave little room to divert resources from one area of livestock research to another without seriously damaging outputs in other areas of livestock research.

Much of the FAnGR research within the CGIAR already involves very extensive partnerships, both with NARS in developing countries and centres of expertise in developed countries and with national and international development agencies. Cooperation and collaboration among CGIAR institutes and between CGIAR institutes and FAO has improved markedly in recent years. That said, there are still a number of programs in which the model of business appears to be too CGIAR centred and there are some notable areas where CGIAR institutes are still working independently when they should be working closely together toward the same goal. The future strategy of the CGIAR should therefore include careful attention to ensuring that important products of CGIAR research are developed in partnership with both experts and stakeholders outside the CGIAR, that activities are centred in institutes best positioned to develop and deliver the outputs desired, and that in all areas the CGIAR coordinates and integrates its activities across institutes.

There are enormous expertise and resources in the developed and to some extent also the developing world available to be harnessed for research in management of FAnGR in the developing world. The traditional model for harnessing such expertise within the CGIAR has been to bring such expertise in as collaborators on CGIAR research. This mode of business reflects the financial reality of CGIAR institutes and the rewards to individual researchers (neither of which are unique to the CGIAR). There is little reward to institutes or individuals in facilitating the development of effective consortia for R&D in which the individuals or institutes takes little or no part. Yet the CGIAR is well positioned to identify global needs and opportunities and to identify teams of people and resources to deliver solutions, even where the CGIAR itself is not well positioned in terms of resources or expertise to participate in the consortium once it is established. The CGIAR should give consideration to how it can reward individuals and institutes for such actions, recognising that in some areas the greatest contribution of the CGIAR may be to help others develop new programs rather than develop its own programs. One route to achieve that might be to establish an actual or virtual research facilitation group with specific mandate to build effective programs of action in FAnGR that have little direct involvement of CGIAR. Such activities would need to be closely coordinated and in full collaboration with FAO and other agencies.

> **FAnGR RECOMMENDATION 12**: The CGIAR should make a substantial increase in its investment in the integrated domains of characterisation, conservation and utilisation of FAnGR. The focus of this increased investment should be in highly experienced staff that design programs, raise awareness and harness international expertise through extensive collaboration, and who can raise substantial external funding to drive long-term programs both within and external to the CGIAR. The new CGIAR investment should not be made by diverting funds from other livestock activities, which remain substantially under-funded within the CGIAR.
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> **FAnGR RECOMMENDATION 13**: The SGRP activities in coordination and promotion of activities in genetic resources beyond PGR should be substantially strengthened. In addition to its role in facilitating collaboration and sharing of information and experience among institutes within the CGIAR, the SGRP is particularly well positioned to coordinate CGIAR collaboration with other agencies to define the needs and opportunities for activities by the CGIAR and other agencies. Examples include the organization of workshops, expert consultancies and reports to identify needs and priorities for research, and the facilitation of the development of large scale, multi-institution funding proposals. Even where the issues being investigated might appear to affect only a single CGIAR institute from the outset, the CGIAR should encourage institutes to work through the SGRP to ensure that the world sees that the CGIAR is working as a coordinated entity and also to ensure that all opportunities for involvement of other institutes are fully explored.
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> **FAnGR RECOMMENDATION 14**: Beyond the specific roles identified in Recommendations 10 and 12, the CGIAR should seek to involve a larger number of its institutes in FAnGR R&D and should ensure that activities in FAnGR are coordinated and cooperative across the CGIAR.

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(Abstracts are provided in footnotes for papers in press)

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[29] **Abstract for Freeman et al., 2005**: Microsatellite markers are commonly used for population genetic analyses of livestock diversity across regions and in a few cases nearly entire continents. However, up to now, combination of microsatellite datasets or comparison of population genetic parameters from different studies and breeds has been proven difficult, if not impossible. Often different genotyping methods have been employed, preventing standardization of microsatellite allele calling. In other cases different sets of markers have being genotyped, providing differing estimations of population genetic parameters. Here, we address the latter situation and illustrate in cattle, with three different sets of microsatellite data, a general approach based on a two step regression method to combine population genetics estimates of diversity (mean number of alleles and unbiased heterozygosity) and admixture. This regression based method is independent of the loci genotyped but requires that there are some breeds in common between the datasets. We show that combination of microsatellite datasets can provide new insights on the origin and understanding of the geographic distribution of the diversity of livestock species which will facilitate the global management of livestock genetic resources.

[30] **Abstract for Gibson and Bishop, 2005**: Improvement and utilisation of host genetic resistance to disease is an attractive option as a component of livestock disease control in wide range of situations. We review the situations where genetic resistance of the host is likely to be a useful component of disease control and provide a framework for deciding whether genetic improvement of resistance is likely to be worthwhile. Discussion is focussed on low input production systems of the developing world where disease resistance is particularly important. We propose an integrated strategy for use of molecular markers in assessing genetic diversity and in utilising and improving host genetic resistance to disease. The integrated approach assures that there is value in the molecular genetic information whether or not it proves useful in genetic selection, a feature that should prove attractive to funding and executing agencies.

[31] **Abstract for Gibson et al., 2005**: Over 6,379 documented breed populations of some 30 species of livestock have been developed in the 12,000 years since the first livestock species were domesticated. These breeds have evolved adaptations that allow livestock production in a wide range of situations, including some of the most stressful environments inhabited by man. These naturally evolved genetic characteristics provide a basket of sustainable solutions to disease resistance, survival and efficient production that have often been ignored in the drive to find technological and management solutions to individual problems of livestock production in low-input systems. It is estimated that 35% of mammalian breeds and 63% of avian breeds are at risk of extinction, and that one breed is lost every week. Although it has not been clearly documented, threats to livestock genetic resources in the developing world appear to be increasing rapidly, driven primarily by rapid change in production systems and extensive use of crossbreeding. Emerging threats, such as implementation of culling policies to prevent spread of commercially important livestock diseases such as foot and mouth disease, and of zoonoses such as BSE and Avian influenza, may risk extinction of breeds in the developed and the developing world.

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[32] **Abstract of Jianlin et al., 2005:** The number of domestic Bactrian camels has been decreasing rapidly in recent years in Central Asia, whereas very little is known about their genetic diversity and relationship. Most of these animals are found today in China and Mongolia. Here, we used 12 microsatellite DNA markers to characterize 140 domestic Bactrian camels from 4 populations of China (n = 84) and 2 populations of Mongolia (n = 56). Genetic diversity, expressed as mean number of alleles and expected heterozygosity (*He*), were similar in all populations. Genetic distances (*DS* and *DA*) indicate closer genetic relationships between populations within each country than between the Chinese and Mongolian populations. Significant differentiation indices (*Fst*) were obtained for all between-country comparisons ($P < 0.01$). However, within countries the *Fst* value between the two Mongolian populations and between four of the six pair-wise comparisons between Chinese populations were not significant ($P > 0.05$). The lack of genetic differentiation among the Chinese populations is possibly a historical legacy of trading along the Silk Road which favored gene flow between populations. For Mongolia, it is possibly the result of interbreeding between populations following transhumance. Our results indicate that the domestic Bactrian camels from China and Mongolia should be considered as distinct populations in conservation and breeding programs.

Table II.1. List of animal species used for food and agriculture

[a] = not domesticated; U = unknown

Widespread species

Species	**No. of breeds**
Pig	350
Goat	320
Sheep	850
Cattle	815
Buffalo	70
Horse	350
Donkey/Ass	70
Dromedary	50
Bactrian Camel	6
Llama	2
Alpaka	2
Guanaco[a]	none
Vicuna[a]	none
Chicken	>300
Turkey	>30
Duck	>65
Muscovy Duck	none
Domestic goose	>60
Guinea Fowl	10 varieties
Japanese Quail	>6
Pigeon	150
Pheasant	none
Partridge	none
Ostrich	4 races
Cassowary	U
Nandu[a]	U
Emu	U
Peafowl[a]	none
Mute Swan[a]	U
Cormorant[a]	U
Little Egret[a]	U

Localized species
(many not domesticated)

Banteng
Mithan
Yak
Gaur
Tamaraw
Kouprey
Anoas
Rabbits
Agouti
Capybara
Coypu
Giant Rat
Grasscutter
Hutia
Mara
Paca
Vizcacha
Chinchillas
Pacarana
Springhare
Rock Cavy
Salt-Desert Cavy
Solomon Islands Rodents
Giant New Guinea Rat
Porcupines
Kiore
Soft-Furred Rat
Giant Squirrels
Squirrels
Colour Rat
Spiny Rat
Bamboo Rat
Red Deer
Mouse Deer
Muntjac
Water Deer
Duiker
Lizards
Green Iguana
Black Iguana
Elephants
Bees
Snails
Crocodiles
Silkworm
Mink
Fox
Nutria
Guinea Pig

Table II.2: Contrast of biological and technical factors between agricultural plants and animals

(Note that these are broad generalisations applying to the majority of the dominant crop and livestock species. Important exceptions occur for most attributes in both plants and animals.)

Factor	Plants	Animals
Economic value of production per individual	Very low to low	Moderate to very high
Reproductive rate (number of progeny of a single individual each generation)	High to very high (1000s)	Very low to moderate (10 to 50) except for males of some species where widespread use of artificial insemination is feasible (10,000s)
Generation interval	0.25 to 1 year	1 to 8 years
Cost to collect production phenotype of a single individual or family	Very low to low	High to very high
Cost to collect adaptation or disease resistance phenotype of a single individual or family	Very low to moderate	Very high
Feasibility of testing large number of varieties against each other in a balanced trial	Very feasible (logistically straightforward and relatively inexpensive)	Not feasible (logistically difficult and very expensive)
Importance of G*E	Highly variable	Highly variable
Development of inbred lines	Possible and routine in many species	Some species will tolerate low levels of inbreeding but inbred lines not feasible as tool for genetic improvement
Ability to self fertilise	Possible in many species	Not possible
Availability of clonal propagation	Possible and routine in many species	Technically feasible but too inefficient even for most research purposes
Ability to undertake genetic transformations (GM)	Possible and efficient in many species using a variety of alternative technologies. Gene targeting efficient in some species	Possible in many species; untargeted insertions can be moderately efficient, but gene targeted insertion remains difficult
Ability to store germplasm in vitro	Seed storage feasible for vast majority of species	Feasible for male gametes of many species and for female gametes of some species; storage of embryos technically feasible in some species, but with lower efficiency than gamete storage
Conditions for storage of germplasm	Seeds of most species can be kept for long periods in cool conditions. Some species require tissue culture and in some cases cultures can be stored in liquid nitrogen	All species require storage in liquid nitrogen
Ease and cost of extracting and testing an accession from a gene bank	Generally easy and relatively low cost to extract and test; tens of thousands of accessions tested annually	Difficult and time consuming and because gametes are usually involved, often involves several generations backcrossing to regenerate a relatively purebred line. Testing also time consuming and costly. Accessions of existing genebanks only occasionally removed and rarely, if ever, tested

Table II.3: Contrast of conservation activities between agricultural plants and animals

Activity	Plants	Animals
Maintenance of genebanks	Extensive collections of plant germplasm globally (millions of accessions for hundreds of species). CGIAR manages approx 11% of global accessions in genebanks (FAO, 1996)	Restricted to a small number of developed countries. Mostly frozen semen of a restricted number of breeds of a small number of species. No involvement of CGIAR
Status of *in situ* genetic conservation	Remains an important component of conservation, with increasing attention by CGIAR and collaborators on how to actively implement	Promoted by most agencies including CGIAR as the most viable method of conservation, but limited experience and no clear framework on how to implement in practice. First projects by CGIAR and collaborators just now being initiated
Status of *ex situ* conservation (E*x situ* here means maintenance of live plants or animals for conservation in an environment that is not their normal production system. In PGR terminology *ex situ* would normally include all gene bank activities, both *in vitro* and *in vivo*)	Relatively minor role in conservation of PGR globally. Little activity by CGIAR	A major component of conservation in developed world, often through dispersed networks of rare breeds enthusiasts, but also by direct government subsidy and support. Government maintained research herds for indigenous breeds not infrequent in developing world, but small proportion of breeds under threat covered and most considered of doubtful sustainability. No CGIAR activity
Ongoing collection of indigenous and wild germplasm	In CGIAR and more generally, activity is at lower levels than previously, but still significant efforts, particularly in neglected species	Very little activity outside of developed world. Low levels of activity in developed world. No activity in CGIAR
Characterisation of indigenous germplasm	Extensive programs to evaluate material in gene banks globally, including within the CGIAR. Given the very large numbers of accessions, the proportion of material that has been extensively evaluated remains quite small	No characterisation of germplasm in genebanks underway. Widespread but largely unstructured activity with indigenous livestock breeds *in situ* or in research farms. Most important characteristics not recorded and few well designed trials
State of global databases	Relatively advanced databases of CGIAR and other genebank holdings, increasingly including data	FAO and CGIAR run complementary databases. FAO database contains country controlled data, with very little

	on characterisation and functions to access GIS information	information on characteristics of most breeds. CGIAR database synthesises peer review and grey literature, but has limited functionality and limited to few species and one region (Africa)
Status of international policy development	Well advanced with recent ratification of the International Treaty on Plant Genetic Resources. CGIAR played and continues to play an important leadership role in policy development	Essentially limited to the requirements under the CBD, which, as in the case of plants, is deemed generally unsuited to agricultural genetic resources. Pressure to develop an international policy framework growing, though FAO as yet has no instruction from countries to actively develop a policy framework. CGIAR has a small amount of supporting research in collaboration with FAO and others
Status of national policy	Very mixed, but generally lagging behind status of international policy. CGIAR active with collaborators in R&D to support countries develop effective policy frameworks	Many countries have no national policy and those that do have inadequate policy. CGIAR has a very low level of activity with collaborators to provide R&D to back policy debate
Lead scientist (Postdoctoral fellow and above) investment by CGIAR in characterisation and conservation activities, including policy development	56 FTE[33]	5.8 FTE
Lead scientist investment by CGIAR in genetic utilisation of PGR and FAnGR	N.A. (20 FTE in IPGRI programs)[34]	6.5 FTE

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[33] Based on FTE identified working on the 11 CGIAR gene banks as identified in the current proposal for upgrading CGIAR gene banks to WHO.

[34] The total number of FTE involved in utilisation of PGR was not available. 20 FTE are employed in IPGRI programs alone. Total CGIAR likely to be well over 50 FTE.

Table II.4: Summary of CGIAR activities related to characterization, conservation and utilisation of FAnGR

ICARDA

Project title and description[1]	**2005 Budget**[2] **($)**	**% core**[3]	**% project**[4]	**Itemised FTE**[5]	**Level**[5]	**% core**[6]	**% project**[6]
1. Book on phenotypic and production characterization of small ruminants (SR) in CAC	23,000	15	85	0.03	Project leader	100	0
				0.09	NPO	100	0
				0.10	Senior researcher	0	100
2. On-farm production characterization of SR breeds in CAC	17,000	18	82	0.03	Project leader	100	0
				0.08	NPO	0	100
				0.10	Senior researcher		100
3. On-farm phenotypic and production characterization of goats in Syria	12,500	12	88	0.03	Project leader	50	50
				0.42	RA	0	100
4. Molecular genetic characterization of goats of Syria	18,000	28	72	0.03	Project leader	90	10
				0.04	Senior molecular geneticist	100	0
				1.0	Junior researcher	0	100
				0.1	RA	0	100
				1.0	Laboratory technician	20	80

IPGRI and SGRP

Project title and description[1]	**2005 Budget[2] ($)**	**% core[3]**	**% project[4]**	**Itemised FTE[5]**	**Level[5]**	**% core[6]**	**% project[6]**
IPGRI and SGRP jointly contribute to the international technical consultation on animal genetic resources conservation strategies to be held in Montpellier, France. Jointly organized by IPGRI, ILRI, ICARDA and the FAO FAnGR group and co-convened by Agropolis, SGRP and FAO.	111,178	12,500	98,678	0.1	Senior scientist, programme assistant	34	66
SGRP providing support to FAO Commission on Genetic Resources on AnGR issues; contributions to State-of-World Report on Animal Genetic Resources.	24,000	24,000		0.2	2 senior scientists	100	
The IPGRI managed Genetic Resources Policy Initiative (GRPI) has supported creation of multi-stakeholder task forces in six countries that are conducting national needs assessments with respect to needs for capacity strengthening and participatory research as inputs for genetic resources policy-making in the countries concerned. Several of theses taskforces have representatives from both governmental and non-governmental organizations engaged in FAnGR-related activities as members of the task forces. A still wider set of people involved in FAnGR-related activities in the countries concerned are being surveyed.	20,000		20,000	pm	Participation of ANGR people in the national task forces		50

ILRI

Project title and description[1]	**2005 Budget**[2] **($)**	**% core**[3]	**% project**[4]	**Itemised FTE**[5]	**Level**[5]	**% core**[6]	**% project**[6]
1. BMZ: Improving the Livelihoods of Poor Livestock Keepers in Africa through Community based Management of Indigenous Farm Animal Genetic Resources	410,000	0	100	0.5	IRS Project Coordinator	0	100
				0.8	0.8 NRS sub-project coordinator	0	100
				1	NRS	0	100
				1	PhD	0	100
2. Univ. Hohenheim, Germany: Community driven breeding programmes in Vietnam using genotypes with high productive adaptability.	6,000	24	76	0.1	IRS Scientist	100	0
3. Exchange Access and Benefit Sharing of AnGR	25,000	24	76	0.2	IRS Scientist	0	100
4. UNEP GEF (PDF-B): Development and Application of Decision-support tools to conserve and sustainably use genetic diversity in indigenous livestock and wild relatives	200,000	0	100	0.2	IRS OPL Project Leader	100	0
5. UNDP GEF: In situ conservation of West Africa Livestock	566,000	10	90	1.2	IRS OPL Project Leader	100	0
					IRS Project coordinator	0	100
6. Characterization of Livestock Genetic Resources of Asia	195,000	30	70	0.2	IRS OPL Project Leader	100	0
				1	IRS Project coordinator	50	50
				0.2	IRS South Asia	100	0

					Representative		
				1	MSc Student	0	100
7. Domestic Animal Genetic Resources Information System (DAGRIS)	33,000	100	0	0.1	IRS project leader	100	0
				0.2	NRS sub-project leader	0	100
				2.3	NRS support staff	100	0
8. Characterization of Livestock Genetic Resources of Africa	160,000	60	40	0.2	IRS OPL project leader	100	0
				0.3	NRS Post-doc	100	0
				3	NRS support staff	100	0
				1	MSc Student	0	100
9. Breeds comparison Ghibe valley, Ethiopia	10,000	100	0	0.1	NRS Post-doc Project coordinator	100	
				0.5	NRS support staff	100	
10. Exchange Access and Benefit Sharing of AnGR	25,000	24	76	0.2	IRS Scientist	0	100
11. BOKU, Austria/Conservation and utilisation of livestock genetic resources to benefit poor farmers	290,000	100	0	1	IRS Project coordinator	0	100
				0.2	IRS Scientist	0	100
				2	PhD Students	0	100
				1	NRS Support staff	0	100
				3	MSc students	0	100
12. ETH-ZIL, Zurich/Developing Optimised Cattle	3,300	0	100	0.1	IRS Scientist	0	100

Breeding Schemes, with a special focus on trypanotolerance, based on the demands and opportunities of poor livestock keepers							
				1	PhD student		
13. Genetics of trypanotolerance	760,400	80	20	1	IRS Post-doc	0	100
				0.05	IRS Scientist	100	0
				0.8	IRS Scientist	100	0
				1	IRS Scientist	0	100
				1	IRS Scientist		
				0.7	NRS post-doc	60	40
				1.4	consultants	0	100
				6	NRS support staff	70	30
14. USAID-KARI-TRC. Performance of trypanotolerance QTL under field challenge.	46,200	20	80	0.05	IRS Scientist	0	100
				0.2	NRS support staff	100	0
				2	PHD student	0	100
15. Genetics of sheep GI nematode resistance	100,100	100	0	0.2	IRS Scientist	100	0
				3.8	NRS	100	0

[1] Recognising that Institutes use different approaches and scales for project budgeting, the choice of project scale is determined by Institute budgeting procedure.

[2] Budget is total project budget for 2005, including all salaries.

[3] Core funding here is deemed to be the sum of the Institute's unrestricted and program restricted funding allocated to the project.

[4] Project funding is income from grants coming to the project.

[5] Itemised FTE (full time equivalents) are broken out by level of staff involved.

[6] Core and project funding here apply to the individual FTE, with same definitions as at [3] and [4]. Where no core or project funding is identified, the FTE refer to a visiting scientist on secondment.

Table II.5: Summary of donor and agency strategies and activities related to FAnGR

Information for agencies named in ***bold text*** *is based on their response to request for information. Information for other agencies based on other sources (mostly author's personal knowledge and web search).*

Donor/Agency	Strategy/Activities
Austrian government	No formal strategy for AnGR. Funds two projects of collaboration between BOKU and CGIAR (ILRI and ICARDA) based on applications received when reinstating its contributions to CGIAR in 2003.
ACIAR, Australia	No formal strategy. Responds on a case-by-case basis to initiatives from our partner countries and agencies. Not currently considering direct FAnGR conservation. Significant interest in characterising and utilising indigenous FAnGR. Recent funding approx AUD$850,000 per annum. Current projects are: *AS1/1997/027: Genetic and immunological characterisation of high resistance to internal parasites in Indonesian Thin Tail Sheep,* being led by the University of Sydney in conjunction with CRIAS and LIPI in Indonesia. 2000-2004. $2.3M total. *AS1/2002/038: Improved productivity, profitability and sustainability of sheep production in Maharashtra, India through genetically enhanced prolificacy, growth and parasite resistance*, being led by the University of New England in partnership with the Nimbkar Agricultural Research Institute in India. This project started in 1998 and will cease at the end of 2005. $1.5M total. *AS2/1999/036: Developing profitable beef business systems for previously disadvantaged farmers in South Africa,* being led by the CRC for Cattle & Beef Quality in partnership with the ARC in South Africa. 2001 - 2006. $1.3M total. (Approx 1/3rd of project is on characterisation of AnGR, remainder on production system and market development).
Asian Development Bank	No known strategy or activity for FAnGR.
African Development Bank	No formal strategy on FAnGR but is approving a total of US$ 14,123,000 in loans and grants (mostly grants) to four countries participating in a UNDP GEF funded project on conservation of West African trypanotolerant livestock, 2005 to 2015.
DANIDA, Denmark	Has historically run a number of projects on poultry and small ruminants FAnGR utilisation. Unable to locate information on current activities on their website.
DFID, UK	No explicit mention is made of livestock genetic resource conservation and utilisation in DFID strategy, though this might feature in future research commissioning. DFID spending on development at a country level is determined in discussion with the governments of those

	countries. None of DFID's country offices is supporting the conservation of livestock genetic resources at current time.
CIRAD, France	Strategy not known. Has several staff based in Montpellier, at ? Burkina Faso, and in Vietnam involved in FAnGR characterisation and genetic improvement. Probably 3 or 4 FTE?
FAO	Has run activities in conservation of FAnGR since 1973. Currently has 4 FTE permanent staff running FAnGR activities. Major current focus is the collation and analysis of the information returned from countries in order to prepare the reports on the State of the World (SoW) for FAnGR, due in 2006. FAO also manages the DAD-IS databases, and a range of related intergovernmental processes. In recent LoA between the Animal Production and Health Division of FAO and ILRI, FAO defines its role as managing the intergovernmental and normative processes, while ILRI's role is as a deliverer of research.
GEF of the United Nations	The UNDP GEF and the UNEP GEF both formally recognise conservation of FAnGR as being a relevant domain of activity within their general acceptance of the relevance of agrobiodiversity. The position of World Bank GEF is not known, but is not thought to be interested in FAnGR activities. UNDP GEF has provided $10,495,000 For conservation of West African trypanotolerant livestock, 2005 to 2015. UNEP has funded $450,000 for a PDF B for systems of *in situ* conservation of livestock in four African and Asia countries. In both cases ILRI plays an executive role.
GTZ/BMZ, Germany	GTZ is executing agency for BMZ and BMZ has no people directly involved in FanGR. R&D on FAnGR by GTZ is in the context of bilateral biodiversity projects and in agricultural research. Key elements of the BMZ/GTZ strategy are: a)Activities on various levels: macro (international platforms), meso (regional and national level) and micro (community based approach); b) Focus on in-situ management and conservation; c) Livelihood approach - management of animal genetic resources as an asset for rural development and income generation; d) Integrated approach - Management of livestock genetic resources connected with plant genetic resources management and nature conservation; e) Public Private Partnership to promote and add value to neglected animal breeds. Current funding is project dependant provided by BMZ at approx 400.000 €, falling steadily to approx 100.000 € by 2007 unless new projects developed. Note that much (in later years, all) of this funding also appears in ILRI budgets since ILRI manages one of the BMZ funded projects. 0.5 GTZ FTE devoted to FanGR (externally funded). Current projects are: • "*People and Biodiversity*" focusing on nature conservation and agrobiodiversity (plant and animal genetic resources); this supraregional project focuses on policy advice, concept development, training and capacity building, mainstreaming, social marketing and technology transfer (2003-2005). • "*Gene flow in animal genetic resources*" in collaboration with University of Hohenheim and FAO. The study aims to quantify

	the international movements of FAnGR (2004-2005). • *“Improving the Livelihoods of Poor Livestock-keepers in Africa through Community-Based Management of Indigenous Farm Animal Genetic Resources”* An ILRI based project with GTZ as a principle collaborator (2004-2007).
IDRC, Canada	The Environment and Natural Resource Management (ENRM) Program support research to secure source of food and water for rural and urban poor and includes a component on local management and control of biodiversity. Within this the current emphasis is on plant genetic resources and a smaller effort on aquatic genetic resources. There is no direct investment in FAnGR, though one IDRC funded project, the Genetic Resource Policy Initiative (GRPI) managed by IPGRI is planning to develop a small FAnGR component.
IFAD	Does not appear to have a strategy on FAnGR. Did express an interest in funding a cost-benefit analysis to support request to AfDB for funding to match GEF project on conservation of trypanotolerant West African Livestock, but that study did not go ahead. No known funding of FAnGR at present.
Rockefeller Foundation, USA	No involvement with AnGR.
SDC, Switzerland	No specific strategy and livestock and FAnGR are not a priority area for SDC. No SDC FTE allocated to FAnGR. SDC’s executing agency, ZIL at ETH Zurich, recently funded ETH for collaboration with ILRI on socioeconomics and genetic aspects of genetic improvement related to utilisation of trypanotolerance in livestock. Approx $80,000 per annum.
SIDA, Sweden	No formal strategy for FAnGR, but some years ago SIDA increased its core funding to ILRI by approx $200,000 to fund collaboration with SLU, Sweden, on capacity development in management of FAnGR. Also finances PhD projects at SLU in Nicaragua and Ethiopia. Approx $140,000 per annum.
USAID, USA	No formal strategy on FAnGR but currently funds one project joint between University Haifa, Israel and ILRI and KARI, Kenya, on testing QTL for trypanotolerance in cattle under field conditions in Kenya, under its CDR program. Approx $65,000 per annum.

CHAPTER III: CONSERVATION OF FISH GENETIC RESOURCES

Roger S.V. Pullin

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Introduction

This paper reviews conservation of fish genetic resources (FiGR) and provides recommendations to the Consultative Group on International Agricultural Research (CGIAR) for strategies in this area of its work. Recommendations are numbered according to their order of mention in the text, and are not in any order of priority. The focus is on target species of fisheries and aquaculture, while recognizing that fish in fisheries and fish on farms require a wide diversity of microorganisms, plants, plankton, corals and other animals to provide them with food, oxygen, waste processing, and shelter. Responsible fisheries and aquaculture require ecosystem-based management. Fish on farms and their supportive biota are part of agrobiodiversity. Most fish in fisheries are wildlife.

Fisheries and aquaculture are vital sources of livelihood and contributors to food security for the poor of the developing world. About 200 million people worldwide depend upon fisheries for their livelihoods (www.fishforall.org). Small-scale fisheries provide about 25% of the world's fish catch, but small-scale fishers are among the poorest of the poor in many developing countries. There is also widespread poverty among small-scale fish farmers and landless fish workers. Fish are an extremely important source of animal-derived protein, health giving lipids and micronutrients for poor consumers. For example, fish provide about 80% of animal-derived protein in human nutrition in Bangladesh. The importance of fish for the poor, in human nutrition and livelihoods, is reflected in the Plan of Implementation of the 2002 World Summit on Sustainable Development (WorldFish, 2002).

Definitions

Conservation is regarded here as an integral part of management. Management of resources implies good stewardship, for maintenance of their integrity and assurance of their future availability (Pullin, 2000). Conservation also means prevention of excessive or wasteful use. Fish means collectively finfish (Pisces) and aquatic invertebrates (principally crustaceans, echinoderms and molluscs). Aquaculture means the farming of fish, and comprises hatchery and nursery operations to produce fish seed (eggs, larvae, fry and fingerlings) and the growout of fish seed to marketable size. Fisheries enhancement has diverse terminology. Restocking usually means rebuilding the spawning biomass of overfished stocks, and stock enhancement refers to the release of fish that will be harvested. Fish ranching and culture-based fisheries are other widely used generic terms. In this paper, all fisheries to which hatchery fish or collections of wild fish are added, with or without habitat modification (for example, artificial reefs or brush parks) are called enhanced fisheries. All other fisheries are called conventional capture fisheries.

Resources must be of actual or potential use. The main use of fish by humans is their capture and farming, for direct consumption as human food or for incorporation in livestock and fish feeds. The other major extractive use of fish by humans is for ornamental purposes, in private and public aquaria. Fish also have many non-extractive uses because of their high cultural significance (e.g. see Posey, 1989). Plant genetic resources (PGR) have been described as ever changing populations of economic species, closely adapted to the natural and human components of the environments in which they are grown, as well as the constant populations of some of the same species that are kept in genebanks (Bunting and Pickersgill, 1996). The same definition applies broadly to all genetic resources for food and agriculture.

However, some of the definitions used to describe broad categories of PGR and farm animal genetic resources (FAnGR) have not yet been commonly applied in the same manner to FiGR. Most fish genebanks are breeding populations of fish (broodstock), usually called 'live fish genebanks'. They are the equivalents of the so-called *in vivo* genebanking for PGR and FAnGR. The terms *in vivo* and *in vitro* (for cryopreserved genetic material) are not yet in common use for FiGR. In this paper, *in vivo* and *in vitro* are used in the same sense as their usage for PGR and FAnGR, as a move towards standardization of terminology.

Unlike PGR and FAnGR on farms, FiGR on farms have not usually been described as *in situ.* In fisheries and aquaculture, *in situ* has usually been taken to mean living freely in open waters, and *ex situ* to mean located in any form of captivity, including on-farm. However, fisheries and aquaculture professionals should note that the Convention on Biological Diversity (CBD – see CBD, 1994) defines *in situ* conditions as: *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*". The CBD defines *in situ* conservation as: "... *conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties*". The CBD defines *ex situ* conservation as "*conservation of components of biological diversity outside their natural habitats*". In this paper, *in situ* means wild and feral fish living in open waters, as well as domesticated fish on farms, distinct from wild types. All other fish in captivity are regarded as *ex situ.* This is consistent with the use of the terms *in situ* and *ex situ* for FAnGR and PGR, and with CBD definitions.

Perspectives on conservation of FiGR

Beyond the historically different terminology applied to FiGR, as discussed above, conservation of FiGR also requires some different perspectives from those for conservation of PGR and FAnGR. First, the relative contributions to world fish supply of conventional capture fisheries, aquaculture and enhanced fisheries, are in a highly dynamic state, as are the relative contributions of the multiplicity of harvested and farmed species. There are huge uncertainties concerning the sustainability and restorability of many conventional capture fisheries, the limits to expansion and sustainability of some forms of aquaculture, and the benefits of some enhanced fisheries.

Second, FiGR comprise very large numbers of species. Fisheries target thousands of species and hundreds of fish species are farmed. Different species are fished and farmed in warm and cold waters and among different developing regions. FishBase (www.fishbase.org) gives the following numbers of finfish species used by humans: in commercial and subsistence fisheries, 4,321; in common use in the aquarium trade (omitting rare and potential use), 3,842; for game (i.e., sport) fishing, 1,134; in aquaculture, 344; as bait, 299; and in traditional medicine, 65. There are no similarly aggregated and easily accessible data for crustaceans, molluscs and other aquatic invertebrates.

Third, there are few well established *in vitro* genebanks for FiGR and none of comparable scale and with international standards comparable to those established for PGR. Finfish sperm and the embryos and larvae of some aquatic invertebrates (chiefly bivalve molluscs) can be cryopreserved under liquid nitrogen. Cryopreservation of sperm has been achieved for at least 83 species of finfish (Tiersch and Mazik, 2000). However, the world's main fish genebanks comprise broodstock collections, only a few of which are supplemented with *in vitro* collections of cryopreserved sperm, mostly in developed-countries. For example, Hungary has such a genebank comprising over 30 distinct wild and farmed strains of common carp, for its national breeding program and related research (Bakos and Gorda, 2001). Broodstock are not genetically stable because captive fish inevitably undergo domestication selection. In fish hatcheries and nurseries, this can act through very high and often little understood mortalities among millions of progeny, often obtained from small effective breeding populations.

Fourth, most FiGR are still categorized at species level. The exceptions to this are the distinct fish strains and hybrids that have been developed for a limited number of farmed fish species [e.g., common carp (*Cyprinus carpio*) and rainbow trout (*Oncorhynchus mykiss*)] and for some freshwater ornamental species. For many farmed fish, the mating of individual fish is not managed closely and broodstock are often allowed to mate at random. The use of pedigreed individuals is rare.

Aquaculture and fisheries statistics

A*quaculture statistics*

Aquaculture statistics are compiled mainly at the species level, without indicating contributions of hybrids, distinct fish strains, and other genotypes. This hinders assessment of the relative importance of these FiGR. Aquaculture production from interspecific hybrids is commonly reported under a generic name followed by "spp." and reporting for some single species probably involves hybrids or multiple species (Bartley et al., 1997).

> **FiGR RECOMMENDATION 1:** The CGIAR should explore with partners how to identify, in aquaculture production and value statistics, contributions from fish hybrids, distinct strains and other distinct genotypes. Standard terminology will be needed, as well as the development of national and international institutions for certification of the identity and provenance of farmed fish.

Fisheries statistics

Most fisheries statistics do not identify contributions from enhanced fisheries. A new classification of fish production practices is currently under development for statistical purposes, and a version of this is presented here, modified to suggest their various requirements for FiGR (Table III.1).

Table III.1. Fish production practices, indicating their main (and other) requirements for fish genetic resources. C = captive, undomesticated. D= captive, domesticated. W = wild type. Source: modified from material supplied by FAO, and with genetic resouces categories and requirements added.

PRODUCTION FROM:	**DESIGNATION**		
	AQUACULTURE	**CAPTURE FISHERIES**	
		Enhanced	**Conventional**
Hatcheries and nurseries	**C , D , (W)**	**C, W**	
Fish farms			
- Ponds	**C, D, W**		
- Tanks, Raceways, Cages	**C, D**		
- Pens, Barrages, Tidal ponds	**C, D, (W)**		
- Poles, Ropes and Net bags for molluscs	**(C), W**		
Fattening wild caught organisms (e.g. tuna)	**W**		**W**
Stocked lakes, dams, reservoirs and rivers	**C, (D), W**		
Unstocked lakes, dams, reservoirs and rivers:	**W**		
Integrated rice–fish systems:	**C, D, W**		**W**
Brush parks:	**(C), W**		
Fish aggregating devices			**W**
Short-term holding of captured organisms (e.g., lobsters, crabs)			**W**
Ranching		**C, W**	
Artificial reefs, with or without exploitation rights		**(C), W**	
Recreational inland fisheries		**(C) W**	**(C) , W**
Open access waters, with or without exploitation rights			**W**

FiGR RECOMMENDATION 2: The CGIAR should explore with partners how to identify, in fisheries production and value statistics, contributions from enhanced fisheries. It is important to identify accurately the species used. It is also important to identify the sources of fish that are stocked. The broad categories suggested are as follows: wild, from the same locality to be stocked or from a different wild population; bred in captivity but not distinct from the wild population to be enhanced; or bred in captivity and distinct from the wild population to be enhanced. Standard terminology and criteria for distinctiveness will be needed.

FiGR in conventional capture fisheries

Fisheries in crisis

About 70% of world fish supply derives from conventional capture fisheries and their major contributions will continue even as those from aquaculture continue to expand. Fisheries science pioneered the concept of sustainable yields from renewable natural resources and is a leader in the global transition towards ecosystem-based management of natural resources (FAO, 2003). However, the conservation elements of fisheries science have been implemented so poorly that about two-thirds of the world's conventional capture fisheries have become fully exploited or overexploited and many fisheries ecosystems are seriously damaged, especially by overfishing and destructive fishing methods (e.g. see Pauly and Maclean, 2003).

Genetic impacts of fishing

Conventional capture fisheries harvest mostly indigenous species, though there are some important inland fisheries for alien species, hybrids and feral fish; for example, the tilapia that have escaped from farms or been released in many countries (Costa-Pierce, 2003). Therefore, FiGR for conventional capture fisheries are mostly wild types, plus some feral populations.

Fishing is usually highly selective in terms of individual fish size and individual or group behaviour. Overfishing could therefore be expected to lessen fish genetic diversity. A recent review, drawing mainly on examples of heavily fished cod and other gadoid stocks, concluded that marine fisheries probably cause greater losses of within-species genetic diversity than any other human activity (Kenchington, 2003). That may well be so, but evidence for significant losses of FiGR through conventional capture fisheries is limited. Genetic change due to fishing pressure has been implicated in the progressively smaller sizes of fish harvested in a wide range of fisheries (including those for cod, plaice, salmon, tilapia, trout and whitefish), but non-genetic factors have usually been admitted as alternative or contributory causes (Sheridan, 1995). The main example of reduced genetic variation through overfishing is that for the orange roughy (*Hoplostethus atlanticus*) fishery in New Zealand, where mean heterozygosity fell significantly as biomass was reduced by 60-70% (Smith et al., 1991). Overall, there are few such clear-cut examples of losses of genetic diversity due to fishing (Smith, 1994). This might reflect the limited studies made so far, especially for the small-scale, coastal and inland, fisheries that are typical of tropical developing regions. Their genetic diversity is little known, mainly because of inadequate national capacity to characterize their hundreds of target species.

Conservation of FiGR in fisheries

Concepts and methodologies for conservation of wild FiGR are well established (e.g see Nielsen and Powers, 1995). Wild fish gene pools are subdivided, largely as a result of genetically determined behaviour in life history strategy. Ideally, each discrete fished group should be managed separately to maximize conservation of genetic diversity (Maclean and Evans, 1981). Much of the basic research in this field has been on diverse populations of anadromous salmonid species that have a high degree of geographical separation, especially for the freshwater part of their life histories (e.g. see Waples, 2001; Koljonen, 2001). A classification of conservation units has been proposed, based upon gene flow (Wood and Holtby, 1998). There is also extensive information on the population genetics of the target species of large-scale commercial fisheries and the implications for fisheries restoration of rates of fish population decline, variations in spawning biomass etc., have also been much studied (Hutchings, 2001). Some marine invertebrates exploited by fisheries have more localized and distinct stocks than the majority of exploited finfish as well as more cryptic speciation, because of the relatively low mobility of their larvae and adults (Thorpe et al., 2000).

Most fisheries management is based upon assessment of spatially and temporarily discrete and accessible fish stocks, with genetic characterization sometimes used as an aid to their identification. However, maximizing harvested biomass is the overriding objective of most fisheries management, with conservation of FiGR *per se* usually coincidental or lacking. In more responsible fisheries, conservation units would actually *become* the management units. There are some hopeful signs. For example, fisheries certified by the Marine Stewardship Council (www.msc.org) contribute to conservation of FiGR, whether they have this as an explicit goal or not. The same applies to local, national and international organizations that encourage responsible collection and care of ornamental fish. Aquatic protected areas are also very important contributors to conservation of FiGR (e.g. see Côté et al., 2001). Overall, there is a great need for fuller integration of conservation genetics into fisheries management, especially in developing countries. This should be part of the ecosystem-based approach to fisheries management and, in particular, the establishment and management of adequate aquatic protected areas.

> **FiGR RECOMMENDATION 3:** The CGIAR should explore with partners how to contribute to the integration of FiGR conservation into fisheries management, by prioritizing this as an explicit component of ecosystem-based fisheries management and as an explicit goal in the establishment and management of aquatic protected areas. This will require expansion of the collation and sharing of population genetics data, based largely on the use of molecular genetic markers, and the development of decision support tools, which are urgently needed.

FiGR in aquaculture

Genetics in aquaculture

With a few notable exceptions, such as common carp and rainbow trout, most farmed fish species have very short histories of domestication and genetic improvement compared to crops and farm animals. For most farmed species of Chinese and Indian carps, reliable production of fish seed in hatcheries, from broodstock raised in captivity, began in the 1970s. For penaeid shrimp, it began in the 1980s. The first International Symposium on Genetics in Aquaculture in 1982 was followed by rapid expansion of research on farmed fish genetics, with growth of national breeding programs, based mainly on selection (Gjedrem, 1983), with increasing characterization of FiGR for aquaculture (Pullin, 1998). Genetic improvement of Nile tilapia (*Oreochromis niloticus*) became a model species for many warmwater aquaculture researchers and ultimately brought large benefits to resource poor fish farmers and consumers through development and dissemination of genetically improved farmed tilapia (GIFT) and related methodology applied to other species. GIFT were bred by selection, from a synthetic base population, developed from wild African and farmed Asian strains. GIFT and GIFT-derived strains have become the foundations for national tilapia breeding programs of the Philippines, Thailand and Viet Nam, and have provided genetic material for tilapia research to many countries.[35]

Which fish to farm?

Choosing which species to farm and prioritizing FiGR for aquaculture is not straightforward among the many currently farmed and potentially farmable species, and with the variable highly state of aquaculture development in different developing countries and regions. The People's Republic of China (PRC) accounts for about 85% of world production of farmed fish, with most of the remainder coming from East, South and Southeast Asian countries, Europe, South America and the USA (New, 2003). However, recent and current contributions of fish species and fish farming nations to aquaculture production may be poor predictors of their scope for growth. For example, although Chinese, common and Indian major carps currently dominate world production of farmed finfish, and there is considerable scope for increased carp production farming in Asia, carps have very limited acceptance as food fish in other regions. Moreover, few would have forecast that the PRC, with a traditional preference for carps and a non-tropical climate, would become the world's largest producer of farmed tilapia: about 700,000 tonnes in 2002, with 20% for export (Cutland, 2003).

Native or alien species?

There are unpredictable consequences wherever alien fish species are introduced for aquaculture. In Bangladesh, the farming and stocking of common carp in inland waters has not led to large self-recruiting populations that compete with Indian major carps and other native species, but common carp have caused declines in native fish populations elsewhere: for example in Australia and in North and South America (CBD, 2004a). In Indonesia, the common carp is an alien species, but its distinct and popular farm strains are considered national assets and it is now widely regarded as native. Nile tilapia is likewise gaining wide acceptance as a farmed fish in Asia, with few reports of adverse environmental consequences, and tilapia is becoming a global white fish commodity. Nevertheless, forecasting the ecological and socioeconomic impacts of alien species in aquaculture is always difficult.

Carnivorous finfish?

There are also doubts about the sustainability and scope for growth of farming carnivorous fish, because of the limited future availability of fishmeal and fish oils for their feeds (New and Wijkström, 2002), and for some species because of limited seed supply. For example, in the PRC, about 400,000 tonnes of marine finfish were farmed in 2000, comprising 67 species of which 55 were carnivores. These fish were fed mostly on low value fresh and frozen fish; e.g., roundscad (*Decapterus maruadsi*), saurel (*Trachurus japonicus*), and sardine (*Sardinella* spp.). Hatchery seed production was technically infeasible or inadequate for many of the farmed species and collection of wild fry was extensive. The largest farmed production of a single species was 40,000 tonnes of large yellow croaker (*Pseudosciaena crocea*), a carnivore, for which capture fisheries had collapsed. Large yellow croaker hatcheries produced 1.3 billion fry, but some exhibited slow growth, precocious maturation and reduced resistance to

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[35] ADB. Impact Evaluation Study on the Development of Genetically Improved Farmed Tilapia and their Dissemination in Selected Countries. Asian Development Bank: Manila. (in press).

disease, attributed to inbred broodstock. Attempts to cross such broodstock with wild types largely failed, because of difficulties in obtaining the latter (Hong and Zhang, 2001).

The collection of wild carnivorous fish, for fattening in captivity, is also expanding (Ottolenghi et al., 2004), but again the future availabilities of feeds and of adequate quantities of wild caught sub-adults are uncertain. Some low value fish species used to feed carnivorous fish are direct contributors to human food security, especially for poor consumers. Moreover, although aquaculture is contributing increasingly to the live reef finfish trade in the Asia-Pacific region, this can exacerbate overfishing of wild stocks, through collection of juveniles as seed and other fish as feed (Sadovy et al., 2003).

Crustaceans and molluscs?

Over 60 species of crustaceans are farmed (Pullin et al., 1998). There are similar uncertainties to those mentioned above for finfish concerning the farming and fattening of carnivorous crustaceans, including crabs and lobsters. The giant freshwater prawn (*Macrobrachium rosenbergi*) is farmed in over 40 countries and appears to have an assured future in freshwater aquaculture, based upon sound hatchery technology and use of a wide variety of feeds to match its omnivorous feeding habits (New, 2002). However, fuller characterization and more effective conservation of its wild genetic resources in the Asia-Pacific region will be essential for their use in future breeding programs (Mather and de Bruyn, 2003). Moreover, the introduction of freshwater crustaceans as alien species outside their native ranges often has severe adverse ecological impacts and should be strongly discouraged.

Responsible farming of penaeid shrimp has substantial scope for growth. Penaeid shrimp are detritivorous/omnivorous species and command high prices. Where coastal pond farming of penaeid shrimp has suffered periodic failures, because of disease and other problems, it has become apparent that there are few alternative, low trophic level fish to farm in such areas. Among the finfish in the Asia-Pacific region, only mullets (Mugilidae) and milkfish (*Chanos chanos*) qualify, and their markets are limited in many countries. Farming the sea bass (*Lates calcarifer*), which is brackish- and freshwater tolerant, has been seen as an alternative to shrimp, but it is a carnivore. Salt-tolerant tilapia strains and hybrids are being developed in attempts to provide a more widely acceptable omnivorous/herbivorous fish to farm in brackishwater coastal ponds, though the possible ecological impacts of success have not been adequately appraised. Despite their dominant position in brackishwater aquaculture, domestication of shrimps and other crustaceans has not progressed far and much more research is needed on the characterization, conservation and use of their genetic resources.

From their low trophic levels and easy husbandry, filter-feeding molluscs (e.g., clams, cockles, mussels, oysters and scallops) should be excellent fish to farm in developing countries. However, they are very vulnerable to water pollution and accumulate heavy metals, other pollutants and pathogens from polluted waters, as well as toxins from red tide and other harmful algal blooms. Because of food safety concerns, the scope for growth of bivalve mollusc farming is somewhat uncertain in many developing countries, though new initiatives continue, mostly with oysters (*Crassostrea* spp.) and mussels (*Perna viridis*) [e.g. see Kripa et al., 2001].

Responsible aquaculture

Aquaculture is the main hope of many developing countries for increasing and sustaining contributions of fish to their food security, especially for poor consumers (ADB, 2004). Overall, there is probably greater scope for growth of aquaculture in inland waters than in coastal and marine waters, despite the latter's very extensive areas and the scarcity of freshwater in many countries. Brackishwater and marine aquaculture often carry high risks because of adverse climatic events, unpredictable water quality, and unmanageable proliferation of pathogens, predators, red tide and other harmful organisms. Fishponds on farms and other freshwaters appear more manageable as fish habitats than saline waters. Freshwater aquaculture can add value to scarce water resources, though integration of fish production with their other uses on-farm, in irrigation systems or in waste processing.

Poor siting and poorly controlled expansion of aquaculture have severe environmental impacts (Pullin, 1993). For example, penaeid shrimp farming acquired a bad reputation because of large-scale conversion of mangroves to shrimp ponds and bad husbandry, including the spread of diseases and irresponsible use of antibiotics. A general transition to more responsible aquaculture is now underway, following the FAO Code of Conduct for Responsible Fisheries (CCRF), [FAO, 1995] and its guidelines for aquaculture (FAO, 1997), which also cover enhanced fisheries. CCRF Article 9.3.1 contains explicit provisions for the conservation and use of FiGR in aquaculture and enhanced fisheries. It calls upon States to: "*conserve genetic diversity and maintain integrity of aquatic communities and ecosystems by appropriate management*" and to undertake efforts "...*to minimize the harmful effects of introducing non-native species or genetically altered stocks for aquaculture including culture-based fisheries into waters, especially where there is a significant potential for the spread of such non-native species or genetically altered stocks*.....(and)..... *to minimize adverse genetic, disease and other effects of escaped fish on wild stocks*".

There is also much recent literature in support of responsible and ecological aquaculture (NACA/FAO, 2000; Creswell and Flos, 2002; Costa-Pierce, 2002), and a growing movement for organic aquaculture is promoting the farming of low trophic level fish (e.g. FAO, 2003 and the organic aquaculture website[36]). Domestication of some herbivorous/omnivorous fish species that are entirely new to aquaculture is therefore probable. There are a few marine candidates for this (e.g., rabbit fish, *Siganus* spp.), but most development will probably be with freshwater species. Commentaries on new species for marine and brackishwater aquaculture tend to focus on carnivores, and often fail to consider adequately the constraints to feeding them (Klinkhardt, 2004). The farming of carnivorous fish will undoubtedly continue to various extents, depending upon availability of feed and seed and market opportunities. Unlike their terrestrial counterparts (lions, tigers and wolves), carnivorous fish taste very good and have assured markets, even at very high prices. Reductions in the fishmeal (though probably not the fish oil) content of fish feeds are expected, through ongoing nutritional research.

Considering all of these factors, the current major groups of farmed warmwater finfish (carps, catfishes and tilapia) along with penaeid shrimp and some bivalve molluscs (oysters

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[36] www.fw.umn.edu/isees/OrganicAquaculture

and mussels) will almost certainly predominate in the near-term expansion of developing-country aquaculture. Therefore, *in situ* and *ex situ* conservation of FiGR of all these groups merit substantially increased efforts. Conservation of other FiGR for coastal and marine aquaculture requires a broader approach, continuing characterization of the genetic diversity of promising species and focussing on species and waters with the greatest potential for developing responsible aquaculture.

Characterization, conservation and use of FiGR in aquaculture

The primary role of the CGIAR concerning FiGR for aquaculture should be to demonstrate interdependence among characterization of FiGR, their conservation, and their use in genetic improvement: a continuum in research, development and production. The CGIAR and its many partners in the genetic characterization, conservation, genetic improvement, dissemination and evaluation of GIFT have already shown this. However, the CGIAR's future role should be on improvement of methods and approaches along this continuum, rather than on development and dissemination of its own genetically improved fish strains.

> **FiGR RECOMMENDATION 4:** The CGIAR should continue, with appropriate partners, to develop methods and approaches for the characterization, conservation and use of FiGR for genetic improvement of farmed fish. Beyond demonstration of genetic improvement of farmed fish for the advancement of methodology, the CGIAR should not be directly involved in the production and dissemination of genetically improved strains of farmed fish.

Information for stewards and users of FiGR in aquaculture

The increasing application of genetics in aquaculture is creating increasing needs and opportunities for accurate and up to date information on the status and availability of wild and farmed FiGR, including populations of new candidate species for aquaculture. Moreover, there is intense interest in sharing the results of genetic improvement research and, with thorough prior assessment of any environmental risks, the responsible and equitable sharing of germplasm. This requires the sharing of genetic information on wild, research, and farmed populations of fish, among FiGR stewards and users.

> **FiGR RECOMMENDATION 5:** The CGIAR should explore with partners how to establish mechanisms for regular assessment of the status and availability of FiGR for aquaculture and for dissemination of this information on-line. The initial emphasis should be freshwater finfish (principally carps, catfishes and tilapia), marine bivalve molluscs, and marine and brackishwater shrimp.

FiGR in enhanced fisheries

General status

There are no easily accessible global statistics for enhanced fisheries. Their annual yields in the late 1990s were estimated at about 2 million tonnes, mostly from reservoirs in the PRC, Pacific salmon fisheries and inland waters of South Asia (Lorenzen et al., 2001). Between 1984 and 1997, 64 countries reported activities in stocking coastal and marine waters, involving about 180 fish species.[37] Enhanced fisheries for marine invertebrates are well established and awareness of their possible genetic impacts is increasing Caddy and Defeo, 2003). Japan has particularly extensive and diverse enhanced coastal fisheries, involving over 80 species of marine fish, often with provision of artificial reefs. There are, however, many questions and concerns over the economic effectiveness and the ecological impacts of enhanced fisheries. For example, catches of Japanese flounder (*Paralichthys olivaceus*) have not benefited demonstrably from 40 years of hatchery releases and although recent releases of larger hatchery juveniles have shown some returns, there are concerns over the genetic impacts of hatchery fish on wild fish populations and the spread of diseases (Murai and Yuichi, 1998).

Genetic impacts of enhanced fisheries

Enhanced fisheries become especially controversial when the fish released are alien species or indigenous species that are genetically distinct from wild populations for which the conservation of genetic integrity is important, and with which the fish released can interbreed or compete. There are particular concerns when hatchery fish, or wild fish collected off-site, are released at locations that contain unique wild fish populations and communities. Such controversies can be related to aquaculture development, especially where territories and markets are shared. For example, in the Pacific Northwest there is a controversy about the relative merits of salmon farming and salmon ranching. Salmon farming operations there are highly visible and are responsible for escapes of native species (*Oncorhynchus* spp.) and alien Atlantic salmon (*Salmo salar*). Salmon ranching of native species is less visible but also controversial because releases of hatchery salmon could lower effective breeding numbers of wild fish. It has been pointed out that these hatchery fish are mostly first generation fish and thus still effectively represent the genetic constitution of wild stocks (Brannon et al., 2004). This does not always apply to hatchery releases and transfers of wild stocks for enhanced fisheries. For example, many localized, self-recruiting wild populations of marine invertebrates, for example bivalve molluscs and sea cucumbers, represent high intraspecific genetic diversity, which could be rapidly and irreversibly changed by hatchery releases or transfers of wild fish from elsewhere (e.g. Uthike and Purcell, 2004).

Recommendations and guidelines for conservation of genetic diversity in enhanced fisheries have been widely published (Bartley, 1999; Taniguchi, 2003). They include provisions similar to those for managing broodstock for aquaculture, particularly the use of effective breeding numbers large enough to avoid genetic drift. The main goal for broodstock management in enhanced fisheries is usually to keeping hatchery fish genetically close to wild types. Such enhanced fisheries are promoted as means for conserving or re-establishing natural populations. However, it has long been recognized in aquaculture that what is sometimes called “domestication selection” can be rapid (Doyle, 1983), and the same applies to captive breeding for enhanced fisheries. Captive broodstock and the early life history stages of captive bred fish must adapt to the water quality, feeds, disease challenges etc. in hatcheries and nurseries. In addition, purposeful genetic alterations to hatchery fish are sometimes sought, such as incorporation of genetic tags or production of sterile fish.

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[37] Born, A.F. , Immink, A.J. and D.M. Bartley. Marine and coastal stocking: global status and information needs, p. 00-00; Chapter 2. In *Marine Ranching*. Food and Agriculture Organization of the United Nations: Rome. (in press).

Because hatchery fish interact with wild populations, in natural and modified ecosystems, for which wild species abundance and diversity baselines are continually shifting, the monitoring of enhanced fisheries gives only location-, time-, and species-specific snapshots of genetic impacts. Findings vary greatly. For example, a study on red sea bream (*Pagrus major*) in Japan found no genetic effect of hatchery fish on wild populations (Kitada and Kishino, 2004). Hatchery cod (*Gadus morhua*) releases in Norway resulted in large initial increases and later declines in a rare allele used to mark them (Jorstad, 2004). In the USA, hatchery steelhead (*Oncorhynchus mykiss*) compromised conservation of some wild populations (Reisenbichler et al., 2004).

Precaution for responsible enhanced fisheries

The key requirement for development of responsible enhanced fisheries is precaution. This costs time and money and requires strong political will. New technology, particularly hatchery technology, is usually attractive to politicians and the public, and naturally also to those with vested interests in its rapid application. The consequent lack of adequate prior appraisals of fisheries enhancement can sometimes resemble that for introductions of alien aquatic species. The history of the latter is not encouraging here, because well formulated codes of practice for responsible introductions and transfers of alien aquatic have long been available but hardly ever correctly used. Cautious, stepwise development of enhanced fisheries is essential and will require internationally applicable instruments, as recently recommended (Molony et al., 2003).

FiGR for enhanced fisheries include native and alien species, as wild types or as fish that have undergone domestication (usually to an unknown extent), and as fish that have been purposefully genetically altered. Every enhanced fishery is unique. Conservation of FiGR for enhanced fisheries must therefore be appraised on a case by case basis, though collation and analysis of results from multiple examples will help progressively with future appraisals and improvement of guidelines. In the same manner as for conventional capture fisheries, development of responsible enhanced fisheries will require fuller integration of conservation of FiGR into fisheries management, and prioritizing conservation targets over for hatchery seed and fish production.

> **FiGR RECOMMENDATION 6:** The CGIAR should contribute towards methods for precautionary planning and conduct of responsible enhanced fisheries, through research on domestication selection and genetic alteration of hatchery fish, and on the genetic impacts on wild populations of stocking hatchery fish and wild fish from other locations.

Threats to FiGR

Finfish are the world's most threatened vertebrate wildlife of high economic significance, chiefly because of widespread degradation and loss of their habitats. The three most serious IUCN Red List categories of threats to species are critically endangered (CR), endangered (EN) and vulnerable (VU). Finfish species totals in all these categories increased from 1996 to 2000: CR, 130 to 152; EN, 125 to 144; and VU, 382 to 447 (for data, see Froese and Torres, 1999). The 1996 and 2000 totals for these categories plus all other categories of threat and loss (defined as, actual extinctions, lower risks and data deficient cases) increased from 1,128 to

1,249 species. FishBase indicates that 255 of the 743 most threatened finfish species (CR+EN+VU) are used by humans and that some of these species have more than one use. The ranking of these uses, in terms of their numbers of threatened species are: fisheries, 144; aquarium trade (ornamental fish), 125; game (i.e., sport) fishing, 70; aquaculture, 24; traditional medicine, 12; and bait, 3 (personal communication to author[38])

FishBase also shows that of the 743 (CR+EN+VU) IUCN Red Listed finfish in 2000, 556 (75%) are primary freshwater species, with another 26 secondary freshwater and 33 diadromous species. This means that 615 (83%) of the most threatened finfish species spend all or part of their lives in freshwaters. For comparison, there are only 22 (3%) correspondingly threatened brackish/marine and 104 (14%) marine finfish species. Similarly, there are in general more serious and extensive threats to freshwater crustaceans and molluscs species, especially for instance, freshwater mussels. However, many estuaries, mangroves and sea grass beds that are important nursery areas for commercial fish species are among the most exploited and threatened of aquatic ecosystems (Blaber, 2002).

The most important FiGR for fisheries and aquaculture are located *in situ* in open waters. For example, wild tilapia genetic resources are all *in situ* in African waters, apart from some limited genebanking. Their conservation is of immense importance for the future of tilapia farming in Africa and worldwide. There is high intraspecific diversity of Nile tilapia across much of Africa. Several tilapia species have high capabilities for salt tolerance. Only one tilapia subspecies (*Oreochromis urolepis hornorum,* found only in the Wami River, Tanzania) yields 100% male progeny in all interspecific hybrid crosses. Many such FiGR are poorly monitored in open waters and are some are seriously threatened (Piers, 2002).

Throughout most of its history, fish conservation has been conceived and implemented largely at the species level, but conservation genetics is becoming the dominant perspective, especially for endangered species. A general review of the use of molecular genetic information for conservation of endangered species has chinook salmon (*Oncorhynchus tschawytscha*) as an illustration (Hedrick, 2004). Sturgeon (*Acipenser* spp.) fisheries have been cited as an example of how molecular genetics could assist compliance with the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as well as accurate product description and fair trading (De Salle and Amato, 2004).

Countermeasures

Countermeasures to threats to FiGR must focus primarily on *in situ* conservation in open waters, with complementary genebanking as needed. *In situ* conservation in open waters has both operational and opportunity costs. For example, Lake Malawi contains about 1,000 unique endemic cichlid species. Their conservation requires prohibition of introductions of alien species and genetically altered fish, great precaution with respect to proposals for enhancement of fisheries for native species, and exclusion of aquaculture. However, Lake Malawi cannot be for conservation alone. Its conventional capture fisheries provide essential livelihoods and contributions to national food security and its governors are under pressure to increase these benefits.

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[38] IUCN and FishBase data supplied by Armi Torres and Christine M.V. Casal of the WorldFish Center.

Sustaining conservation of FiGR in such circumstances requires that the operational costs of conservation measures and the opportunity costs of restricting access to or use of their habitats be shared, and not only through one-time collaborative projects, debt-for-nature swaps and other mechanisms, but on a continuous basis. Users and inheritors of such resources must pay their stewards, in order for all to share the benefits. The main constraints here are institutional, not biotechnical. Despite significant advances in conceptualizing the sharing of costs and benefits of genetic resources, chiefly through the provisions of Article 8j of the CBD, attempts around the world at sharing the benefits of FiGR have been called "a work in slow progress" (Greer and Harvey, 2004).

Restrictions on use of inland and coastal waters for conventional and enhanced fisheries and aquaculture often have had little success. In many cases, they are not socially or politically possible. However, there is still scope for exploring possibilities for establishing aquatic protected areas that are completely off-limits to and isolated from the influences of fishing, farming and other human activities. This could be financed as a twin goal with financing of the more obvious goal of fish production. This will not be possible in many river basins and coastal areas because of lack of suitable sites and the connectivity between habitats for important wild FiGR and the fishing and farming areas. However, this approach should definitely be explored for long-term *in situ* conservation of FiGR in open waters. It is a necessary insurance against the high probability that increasingly responsible fisheries, aquaculture and other sectoral uses of natural resources, will develop too slowly and to too limited an extent to avoid losses of important FiGR.

Another necessary insurance is the expansion of *in vivo* and *in vitro* genebanking of important and threatened FiGR. This should be decentralized and preferably undertaken mainly in the countries of origin of the FiGR. The complementary role of *in vitro* genebanking in conservation of threatened FiGR has been well recognized in developing and developed countries, but with little investment so far (Harvey et al., 1998).

Proposing these insurance measures is not a counsel of despair with respect to conservation of FiGR in the natural environment and indeed in fishing and farming areas. They are proposed as prudent actions to secure future availability of important FiGR, while striving for the increased responsibility in fisheries and aquaculture that is vital for FiGR conservation in general. Policymakers face hard choices in striving for increased responsibility in fisheries and aquaculture. For example, development of tilapia farming is seen as an important contributor to livelihoods and nutrition in Kwazulu Natal, one of the poorest regions in South Africa. The hard choice is between an 'anything goes' policy that allows farming of alien species (such as Nile tilapia), and policies that restrict farmers to use native tilapia (principally, *Oreochromis mossambicus*). An even stricter policy option is to allow only the farming of local stocks of *O. mossambicus* in their particular watersheds, thereby preventing interbreeding among diverse wild and farmed FiGR (Mair, 2003).

The highest priority areas and threatened FiGR are sub-Saharan Africa for tilapia, other cichlids and African catfishes (e.g. see Lévêque, 1997; Agnèse, 1998; Pullin et al., 2001), East, South and Southeast Asia for carps and Asian catfishes (Dehadrai et al., 1994), and Latin America for a wide variety of characids and other finfish (Carolsfeld et al., 2003). This emphasis on inland waters and freshwater finfish reflects the areas of greatest need for countering threats to FiGR for aquaculture, and the greatest opportunities for expansion of aquaculture and with multiple uses of water resources. It also offers opportunities for more linkages among CGIAR activities in agriculture, agroforestry, aquaculture, farming of animals, fisheries, forestry, and water resources management, as well as with a multitude of developed- and developing-country partners working for conservation of freshwater fish (Collares-Pereira et al., 2002).

> **FiGR RECOMMENDATION 7:** The CGIAR should contribute to countermeasures against the threats to FiGR in inland and coastal waters, through:
>
> a) providing expertise and information to policymakers and managers with responsibility for waters and FiGR of high importance;
> b) contributing to guidelines for establishment of aquatic protected areas that are isolated from fishing, aquaculture, contact with alien species and genotypes, and adverse impacts from other sectors;
> c) contributing to guidelines for establishment of genebanks for threatened FiGR, preferably in their countries of origin; and
> d) collaborative research on institutions for sharing costs and benefits**.**

Fish genomics and transgenic fish

Tilapia is not yet a priority in the National Institute of Health's queue of genomes to be sequenced (www.nhgri.nih.gov) (see also Kocher, 2004). However, the Cichlid Genome Consortium (CGS) (www.hcgs.uhn.edu/cichlid) is developing a new proposal for sequencing of the Nile tilapia genome (www.jgi.doe.gov/CSP/index.html). This proposal describes Nile tilapia as the model perciform fish and emphasizes its importance in developing-country aquaculture and food security. For tilapia and some other farmed fish, there is already a considerable body of shared data on tilapia and other farmed fish, including bacterial artificial chromosomes (BACs) and expressed sequence tags (ESTs) (for example see Katagiri et al., 2001).

Transgenic fish have been produced for about 20 species, including African catfish (*Clarias gariepinus*), Atlantic salmon (*Salmo salar*), channel catfish (*Ictalurus punctatus*), common carp, Pacific salmon (*Oncorhynchus* spp.), rainbow trout (*Oncorhynchus mykiss*), sea bream (*Sparus aurata*), red sea bream (*Pagrus major*) and tilapia (*Oreochromis* spp.) (Beardmore and Porter, 2003). The main purposes are to improve growth rates, by transfer of genes for increased release of growth hormone, and to improve cold tolerance by transfer of genes coding for antifreeze proteins or glycoproteins.

The use of transgenic fish in aquaculture is controversial and widely prohibited, pending evaluation of environmental and other concerns. Gene transfer in aquaculture and the aquarium trade necessitates thorough prior appraisal of possible environmental and socioeconomic consequences and ethical implications. The connectivity of aquatic ecosystems and the difficulty of monitoring and eradicating fish and other aquatic organisms in open waters make strict precaution absolutely essential. Food safety aspects have been reviewed through an Expert Consultation convened by FAO and the World Health Organization (FAO/WHO, 2004).

International protocols for transgenic organisms were developed largely to address concerns over transgenic plants and are not entirely applicable for addressing wider concerns over alien fish, fish hybrids and fish that have genetically altered by whatever means (including selection and chromosome manipulations, not just gene transfer) (WorldFish, 2003). Narrow sense definitions as well as public and official perceptions of so-called genetically modified organisms (GMOs) are an illustration. Most would consider only a transgenic fish to be a GMO, but inter- and intraspecific fish hybrids are also obviously genetically altered organisms (Bartley et al., 2001). The international biosafety debate has centred on new policies and safeguards for transgenic fish (e.g. see Logar and Pollock, 2005). An ICLARM-FAO Bellagio Conference took a broader view and has recommended that "....*in formulation of biosafety policy and regulations for living modified organisms, the characteristics of the organisms and of potentially accessible environments are more important considerations than the processes used to produce them*" (Pullin et al., 1999).

The extensive applications of genomics and transgenic organisms in agriculture (e.g. see Gale, 2002) have few parallels in aquaculture so far. However, fish breeders, like plant and farm animal breeders seek faster growth, increased tolerance to adverse environments, increased disease resistance, better feed conversion, less carcass waste etc. These and other breeding goals for farmed fish will probably be pursued largely through selection, which will increasingly be marker-assisted, and through hybridization. It is not yet clear to what extents their attainment could be accelerated, ethically and safely, through development of transgenic fish. The CGIAR is well placed to contribute to discussions on related policy, equity and intellectual property issues, as a neutral party. At present, the CGIAR does not have a comparative advantage to undertake its own research on fish genomics and on development of transgenic fish.

> **FiGR RECOMMENDATION 8:** The CGIAR should contribute to analysis and dissemination of information on fish genomics and transgenic fish, as well as to discussion fora on environmental, economic, ethical, policy and social issues pertaining to their use in aquaculture. The CGIAR should not at present undertake its own research on fish genomics or on the development of transgenic fish.

Exploring a governance approach

Restoration of conventional capture fisheries has great promise for increased fish production and nutritional benefits, especially in developing regions, but is fraught with economic, social and political difficulties, even where ecologically possible. Aquaculture development often appears an easier route to increased fish production but has many limitations. Enhanced fisheries are often attractive, but their benefits and impacts are poorly understood. Conservation of FiGR must therefore involve continuous reassessment of these three subsectors, as well as near-, mid-, and long-term perspectives. A new approach to fisheries governance, dealing with *diversity*, *complexity*, *dynamics*, and widely different *scales*, is being explored at the theoretical level,[39] through a global network (www.fishgovnet.org), and as initial guidelines for policymakers.[40] Fisheries governance builds upon and broadens co-

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[39] Kooiman, J., Bavinck, M., Jentoft, S. and R. Pullin, editors. *Fish for Life: Interactive Governance for Fisheries*. Amsterdam University Press: Amsterdam. (in press).

[40] Bavinck, M. et al. *Fisheries Governance: a Guide to Practice*. Amsterdam University Press: Amsterdam. (in press).

management and ecosystem-based management. Exploration of its applicability to conservation of FiGR is suggested because it provides for flexibility and inclusiveness to confront uncertainty and change.

> **FiGR RECOMMENDATION 9:** The CGIAR should explore a governance approach to conservation of FiGR, through a theoretical review of its feasibility and, depending upon the conclusions of that review, initiating pilot research projects.

Prioritizing increased responsibility

The future of fisheries and aquaculture depends upon them becoming progressively more responsible, as provided for by the CCRF. Greater responsibility in fisheries and aquaculture is essential for conservation of FiGR and also depends in large measure upon conservation of FiGR. The CGIAR is already contributing strongly to increased responsibility in fisheries and aquaculture but must avoid the "techno-arrogance" (Grimes, 1998) that can accompany pursuit of increased fish production. To contribute to increased responsibility in fisheries and aquaculture should be its explicit primary goal, rather than to increase fish production *per se*.

From an ecological perspective, there is no conflict between increased responsibility in fisheries and aquaculture and increased fish production, especially for conventional capture fisheries where, in most cases, reduced fishing effort and provision of aquatic protected areas will result in larger and sustainable catches. However, overcapacity in fishing fleets, destructive fishing practices, and aquaculture development that exceeds the carrying capacity of inland and coastal waters will continue to prevent realization of many ecologically possible gains. Irresponsibility in aquaculture will continue to involve introductions and use of alien invasive species and genetically altered fish without adequate precaution. Conservation measures for FiGR can become important catalysts for increased responsibility in fisheries and aquaculture. The balance needed here has been well expressed in a highly authoritative review on conservation genetics in fisheries: "*not to advocate an excessively 'purist' perspective*....(but to point to)....*the potential danger that may be associated with thoughtless manipulations that violate the basic goals of conservation genetics*" (Ryman, 1991).

> **FiGR RECOMMENDATION 10:** CGIAR contributions to conservation of FiGR should be planned and executed as catalysts for increased responsibility in fisheries and aquaculture.

The CGIAR and FiGR

The WorldFish Center

The CGIAR has only one international research centre responsible for fish on farms and fish in fisheries, the WorldFish Center (WorldFish) (www.worldfishcenter.org), formerly the International Center for Living Aquatic Resources Management (ICLARM). From the early 1980s, headquartered in the Philippines but lacking its own research facilities, ICLARM worked mainly in sub-Saharan Africa and the Asia-Pacific region, through partnerships with advanced research institutes, national programs, NGOs and others. Its aquaculture research, training and information activities gave high emphasis to the characterization, conservation and use of FiGR.

From 1999, WorldFish has continued this emphasis from new headquarters and research facilities in Penang, Malaysia, with collaborative activities in 26 other countries. ICLARM and WorldFish have contributed much to the CGIAR's Systemwide Genetic Resources Program (SGRP). In 1996, a consultation on FiGR was convened by the SGRP and hosted by IPGRI (Pullin and Casal, 1996). In 2000, ICLARM, through the SGRP, checked and where necessary corrected, all species nomenclature used by CGIAR centres for their inputs to the System-wide Information Network on Genetic Resources (SINGER), and was also a major contributor to an SGRP workshop on genetic resources management in ecosystems (Poulsen, 2001). WorldFish contributes to many international fisheries and aquaculture research and development fora; for example, the Advisory Committee on Fisheries Research convened by FAO.

The development of genetically improved farmed tilapia (GIFT) and the dissemination and evaluation of genetically improved tilapia in Asia have been the largest and longest collaborative activities in aquaculture genetics for ICLARM, WorldFish and their many partners. These efforts commenced in 1986 and are still continuing through successive projects and networking. In 1995, a commentary in a publication normally critical of the CGIAR included the following:

"*Most intensive aquaculture is based on highly uniform populations, and breeding has focussed on short term yield concerns and nothing else. Only in recent years - through the International Centre* (sic*) for Living Aquatic Resources Management (ICLARM) - has an aquacultural development program taken account of the role of genetic resources, both to obtain improved performance and to avoid genetic resource erosion*" (Martinez i Prat, 1995).

GIFT and GIFT-related methodology have made major contributions to fish breeding methodology and training, national fish breeding programs, genebanking, biosafety and other environmental safeguards, and networking (Gupta and Acosta, 2004). The success of GIFT and other genetic research for tilapia farming have also stimulated increasing interest in public-private partnerships for conservation and use of FiGR (WorldFish and IDRC, 2004).

In 1997, WorldFish and its principal Philippine national program partners in the development of GIFT established the GIFT Foundation International Inc. (GFII) as an independent, non-stock, non-profit organization, to continue selective breeding and dissemination of GIFT and to maintain the GIFT breeding nucleus in the Philippines. In 1999, the GFII became allied with Genomar ASA, a private Norwegian corporation and its Philippine subsidiary Genomar Supreme Philippines Inc. (www.genomar.com). WorldFish remains a partner in the GFII and also pursues, with partners in Malaysia and elsewhere, GIFT-related research, maintaining collections of GIFT in the public domain. WorldFish has coordinated Asian regional efforts, patterned after the development of GIFT and the DEGITA, to develop and disseminate genetically improved strains of farmed carp species (WorldFish and ADB, 2002).

WorldFish is the Member-Coordinator of the International Network on Genetics in Aquaculture (INGA). INGA was founded in 1993, based upon the wide international interest generated by the GIFT project for networking in aquaculture genetics research and responsible sharing of germplasm. INGA's membership comprises: national programs, institutes and networks in 13 developing countries of Africa and Asia, 12 advanced scientific institutes in Asia, Australia, Europe, the Middle East and North America, and 3 associate members, including the GFII. INGA members are WorldFish's principal partners in aquaculture genetics research and training.

From 2005, WorldFish has adopted a new program structure. Scientific activities and staff are managed under three so-called disciplines: Aquaculture and Genetic Improvement; Natural Resource Management; and Policy, Economics and Social Science. Each discipline has foci and related thrusts (Table III.2). Under this structure, WorldFish contributions to conservation of FiGR will derive mostly from activities within Natural Resources Management, with interdisciplinary links to Aquaculture/Genetic Improvement and to Policy, Economics and Social Science. Enhanced fisheries research will be interdisciplinary, between Natural Resources Management and Aquaculture/Genetic Improvement. Projects will be categorized under regional and subregional portfolios for Africa, the greater Mekong basin, South Asia, East and Southeast Asia, and the Pacific.

Table III.2. Structure for implementation of the WorldFish Center's 2005-2008 Medium Term Plan. Source: WorldFish Center, Penang, Malaysia.

Disciplines	Focus	Thrusts
Aquaculture and Genetic Improvement	Freshwater and coastal aquaculture; Genetic improvement	Sustainable freshwater aquaculture systems; Environmentally-friendly coastal aquaculture; Mitigation of adverse impacts of alien species; Genetic improvement and breeding
Natural Resource Management	Freshwater fisheries; Marine fisheries; Biodiversity	Conservation of aquatic diversity; Freshwater fisheries in an integrated context; Restoration of capture fisheries; Reversing degradation of coastal habitats
Policy, Economics and Social Science	Social sciences	Economic, policy and social analysis; Aquatic resources planning and impact assessment; Legal and institutional analysis

For inland waters and freshwater fish, WorldFish works mainly in Africa, South Asia and Southeast Asia. WorldFish and its many international and African national program partners continue to contribute to FiGR conservation throughout Africa (Gupta et al., 2004). However, WorldFish has by far its largest African presence in Egypt with large research facilities and numerous staff: 4 internationally recruited and 80 nationally recruited staff. This is highly suitable for work in North Africa (and West Asia) but not for contributions to FiGR characterization, conservation and use in Subsaharan Africa. By comparison, WorldFish staff in Subsaharan Africa comprise one internationally recruited scientist in Cameroon, and one internationally recruited scientist plus 14 nationally recruited scientists in Malawi. In South Asia, most WorldFish activities are centered in Bangladesh. In Southeast Asia, WorldFish works through partnerships throughout the Mekong basin countries. Apart from lacking experience with conservation of FiGR in Latin America and needing to expand its capacity for the same in sub-Saharan Africa, WorldFish is well positioned to expand its contributions to conservation of important and threatened freshwater FiGR.

In marine fisheries and aquaculture, WorldFish and partners have worked mainly in the Indo-Pacific and Caribbean the genetics of fish stocks, biological connections among coral reef systems, and development of enhanced coastal fisheries. WorldFish intends to develop a network of molecular genetics laboratories in developing countries to study the population genetics of coastal fisheries (WorldFish, 2004).

The International Plant Genetic Resources Institute

The International Plant Genetic Resources Institute (IPGRI) (www.ipgri.org) has a staff of about 300 in 22 offices around the world, including its headquarters in Rome. IPGRI facilitates CGIAR interactions with the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA) and is the convening Centre of the SGRP (www.sgrp.cgiar.org). The SGRP meets as an Inter-Centre Working Group on Genetic Resources comprising members from all 16 CGIAR crop, farm animal, forestry, fish and food policy Centres. IPGRI is the chief architect, developer and host of the System-wide Information Network on Genetic Resources (SINGER) which will use Global Biodiversity Information Facility (GBIF) (www.gbif.org) data exchange protocols. GBIF appears to offer the best option for interoperability and linkages among the world's increasingly numerous databases on biodiversity and genetic resources. The development of the SINGER has been a very important contribution from the SGRP, but its poor coverage of FiGR reflects the predominance of PGR in SGRP activities to date. The SGRP should be strengthened to remedy this.

> **FiGR RECOMMENDATION 11:** The CGIAR Systemwide Genetic Resources Program (SGRP) should be substantially strengthened in order to expand its activities with respect to FiGR in the broad context of agrobiodiversity and in particular access to information on FiGR in the Systemwide Information Network on Genetic Resources (SINGER).

In its new strategic directions, IPGRI recognizes that FiGR are part of agrobioversity (IPGRI, 2005). The CGIAR needs to coordinate, harmonize and communicate more clearly its policies on agrobiodiversity, including FiGR, especially in its interactions with the CGRFA and in its public relations. This could be achieved by a new CGIAR unit, located in Rome, for contributing to agrobiodiversity policy, in close collaboration with all CGIAR Centres and other bodies and with FAO, especially the CGRFA, and other partners.

> **FiGR RECOMMENDATION 12:** The CGIAR should establish a unit, located in Rome, to undertake coordination, harmonization and communication of its policies on agrobiodiversity, including FiGR, in close collaboration with FAO and other partners.

The International Livestock Research Institute

The CGIAR Centre for FAnGR is the International Livestock Research Institute (ILRI) (www.ilri.org). The main opportunities for ILRI, WorldFish, IPGRI and partners to explore together in genetic resources conservation are probably common approaches to *in vivo* and *in vitro* genebanking. There is also scope for sharing of experiences and methods among ILRI, WorldFish, IPGRI and partners in the biology of domestication, breeding program design and economic valuation of genetic resources (Rege and Gibson, 2003). These opportunities can be explored through a strengthened SGRP.

The International Water Management Institute

The International Water Management Institute (IWMI) (www.iwmi.org) is the CGIAR's water resources centre, headquartered in Sri Lanka and working in 21 countries in Africa and Asia. IWMI's focus on increasing the productivity of water use in agriculture has obvious relevance for the FiGR that have the sources of that water as their habitat as well as for increasing food production in water itself, through aquaculture and inland fisheries. Historically, IWMI and partners conceived aquatic productivity largely as 'crop per drop'. Participation in the CGIAR Challenge Program on Water and Food has broadened that approach, with Aquatic Ecosystems and Fisheries as well as Integrated Basin Water Management Systems as research themes. Among their expected outputs are: *"Assessments of the ecological functions of key aquatic ecosystems, and valuations of goods and services provided by them, and the costs of ecosystem degradation*" (www.waterforfood.org). This program brought IWMI and WorldFish together for work on hydrology and fish production in the Mekong basin and there is scope for wider collaboration in this and other major river basins.

It will be crucial to recognize explicitly the value of FiGR and other aquatic biodiversity in waters used for agriculture and other purposes. Inland aquatic protected areas can conserve and supply FiGR *and* water. Responsible inland fisheries and aquaculture can add value to freshwaters used for irrigation and other purposes. The CGIAR has recognized some of these possibilities, but largely for increased production of fish, not explicitly for conservation of FiGR (CGIAR, 2002). The future opportunities for collaboration among WorldFish, IWMI, other CGIAR Centres and partners in integrating FIGR conservation and water management can be explored through a strengthened SGRP.

The International Food Policy Research Institute

The International Food Policy Research Institute (IFPRI) (www.ifpri.org), located in Washington DC, is a leading contributor to CGIAR policies and plans, including those relating to genetic resources (Pardey and Koo, 2003). IPGRI's work has focussed more on crops and farm animals than on food fish, apart from a recent modelling exercise with WorldFish on future projections for fish supply (Delgado et al., 2003). There is much scope for further IPGRI contributions to policy research on genetic resources, including FiGR, again principally through the SGRP.

CGIAR partners

The Food and Agriculture Organization of the United Nations

The Food and Agriculture Organization of the United Nations (FAO) (www.fao.org) contributes to the conservation of FiGR through a wide range of activities and services. FAO member states meet as the FAO Committee on Fisheries, which has a Subcommittee on Aquaculture engaged in the development of guidelines for sustainable aquaculture. An FAO Expert Consultation (FAO, 1993) and, in partnership with ICLARM, a Bellagio Conference were milestones for discussion of FiGR policy (Pullin et al., 1999). FAO's activities in fisheries and aquaculture are determined by its member states. Great emphasis is being given to fuller implementation of the CCRF. Exploration of a catalytic role for conservation of FiGR towards increased responsibility in fisheries and aquaculture fits well here.

The FAO Fisheries Department is at the hub of a complex system of international and regional fisheries and technical bodies. It strongly promotes precaution and responsible behaviour with respect to introductions and transfers of alien species and farmed aquatic organisms. It joins other FAO Departments and Divisions, including the Sustainable Development Department and the Animal Production and Health Division, in Interdepartmental Groups to coordinate work on overarching issues, for example biosafety and biotechnology. The FAO Fisheries Department provides global information services through a variety of mechanisms: principally its Fisheries Library, Fisheries Global Information System (FIGIS), on-line access to global aquaculture and fisheries statistics (FISHSTAT+) and wide linkages, including participation in the FishBase information system. These facilities have yet to address specifically the structuring and dissemination of information at the genetic level. To remedy this, FAO and others, principally the World Fisheries Trust (WFT) conceived and began initial development of an Aquatic Animal Diversity Information System, later renamed as Fisheries Information Network for Genetic Resources. However, this has not yet progressed beyond studies on possible structures and linkages, standardization of terms and proposals for case studies.

The FAO Commission on Genetic Resources for Food and Agriculture (CGRFA) has focussed most its activities to date on PGR, with recent steps to cover FAnGR, through international and regional agreements and fora, state of the world reports and global plans of action. Coverage of FiGR remains under discussion by the CGRFA, with the CGIAR envisaged as a partner (FAO, 2004). FiGR could be considered within broad coverage agrobiodiversity, focussing first on major species of farmed fish: bivalve molluscs, carps, catfish, salmonids, shrimp and tilapia. Frameworks could then be established for progressively wider coverage of other farmed fish, conventional capture fisheries and enhanced fisheries.

> **FiGR RECOMMENDATION 13:** The CGIAR should assist the FAO Commission on Genetic Resources for Food and Agriculture towards achieving wider coverage of FiGR within the broad context of agrobiodiversity.

The World Conservation Union

The World Conservation Union (IUCN) (www.iucn.org) is the world's largest international organization for the conservation of nature. Its members include 77 States, 114 government agencies and over 800 NGOs. It operates through commissions, specialist groups and other bodies, at international, national, regional and local levels. Concerning conservation of FiGR, its most important bodies are the Species Survival Commission, the Commission on Ecosystem Management, the World Commission on Protected Areas, and the Commission on Environmental Law. The Species Survival Commission compiles the Red List on threatened species and has established Caribbean Fishes, Coral Reef Fish, Freshwater Fish, Grouper and Wrasse, Salmon, Shark and Sturgeon Specialist Groups. IUCN has many long-standing international joint ventures, partnerships and linkages; for example, with the CBD, the Ramsar Convention, the United Nations Environment Program (UNEP) (www.unep.org) and its World Conservation Monitoring Centre (www.unep-wcmc.org) and the World Wildlife Fund (WWF) (www.worldwildlife.org) which is a leader in innovative financing of conservation (Spergel and Moye, 2004).

IUCN and related organizations have many interests in common with the CGIAR for conservation of FiGR. Fisheries are the world's largest extractive use of wildlife. There is scope for expansion of CGIAR-IUCN collaboration, in striving for increased responsibility in fisheries and aquaculture, with *in situ* conservation of FiGR as a catalyst. There may also be scope for more IUCN-CGIAR collaboration with aquarists, especially public aquaria, for decentralized *ex situ* conservation of FiGR, similar to that established with zoos and rare breed trusts for FAnGR.

The World Fisheries Trust

The World Fisheries Trust (WFT) (www.worldfish.org) is a non-profit, non-governmental organization, based in Victoria B.C., Canada. WFT is a major contributor to conservation of aquatic biodiversity through international projects and consultations. Its work to date has been principally on conservation of genetic resources of migratory finfish, using *in situ* ecosystem-based approaches and *in vitro* genebanking of cryopreserved sperm. Its main project areas have been Latin America and the Pacific Northwest, where has provided technical training in salmon genetic resources conservation to clients ranging from aboriginal communities to the Government of Canada and commercial fish farmers. For these diverse clients, WFT facilitated the collection and genebanking of over 8,000 accessions of unique salmon genetic material. WFT has experience in making arrangements for cryopreservation of fish sperm in establishments that store cryopreserved farm animal sperm. WFT has worked with FAO, the CBD, UNEP and the CGIAR, emphasizing primarily *in situ* conservation and complementary *in vitro* genebanking of FiGR and the importance of equitable sharing of benefits.

International conventions

The most important international convention with respect to conservation of FiGR is the Convention on Biological Diversity (CBD) (www.biodiv.org). From the entry into force of the CBD in 1993, the CGIAR has been strongly represented, mainly by IPGRI and SGRP, at its Conferences of Parties and meetings of its Subsidiary Body on Scientific, Technical and Technological Advice. The CBD has an ongoing program of work on the Biological Diversity of Inland Water Ecosystems and another on Marine and Coastal Biodiversity, derived respectively from Decisions VII/4 and VII/5 of Conferences of its Parties (http://www.biodiv.org/decisions). Historically, these programs were somewhat separate and emphasized ecosystem and species levels of biodiversity, rather than genetic resources *per se*. That has changed through close programmatic linkages, including common goals and targets for conservation of FiGR and fair and equitable sharing of their benefits (CBD, 2004b). CBD Decision VII/4 emphasizes that inland aquatic biological diversity means "*genomes and genes, species and communities, ecosystems and habitats*", includes "in situ *conservation through protected areas*" among its goals, and mentions WorldFish as a collaborator. The CBD's Ad Hoc Technical Expert Group has recommended that assessments of progress towards the CBD's 2010 Global Biodiversity Target include as an indicator: "*trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socio-economic importance*" (CBD, 2004c). There is clearly scope for expanded involvement of the CGIAR in the CBD's inland and marine/coastal programs of work, though the naming of CGIAR centres, such as IPGRI and WorldFish, as collaborators in those programs does not in itself generate funds.

Other important international conventions for conservation of FiGR include the United Nations Convention on the Law of the Sea (UNCLOS) (www.unclos.org), the Ramsar Convention on Wetlands (www.ramsar.org), and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (www.cites.org). UNCLOS has long provided a global framework for protection and management of the marine environment and its resources, including marine life. The Ramsar Convention operates in close cooperation with the CBD and defines wetlands very broadly, essentially including most inland and inshore waters and adjacent lands, such as marshes, mangroves and coral reefs. There are over 1,100 Ramsar sites (i.e., wetlands of international importance, afforded special protection to conserve their biota) covering over 100 million ha in 133 countries. The presence of unique, endangered or otherwise important fish populations is recognized as sufficient basis for establishment of a Ramsar site. CITES prohibits or restricts trade in endangered species, and in some cases subspecies and distinct populations, working closely with the CBD, IUCN and related organizations. CITES is currently pioneering a provision for a global minimum size limit on exported seahorses (Vincent, 2004). There is scope for increased CGIAR collaboration with all of these conventions: for example, to document the extent to which important FiGR are being conserved in Ramsar sites and other aquatic protected areas and to contribute to assessing needs and opportunities for additional protection.

FishBase

FishBase was started by ICLARM and its partners and has become the world's largest database on the biology and use of finfish, covering at present 28,866 species, with user entry through scientific nomenclature or common names in over 200 languages (Froese and Pauly, 2000). FishBase is a free information system. Its website is currently receiving about 10 million hits per month. The FishBase information system is structured around a consortium of 8 institutes: FAO, WorldFish, and national museums and universities in Belgium, Canada, France, Germany, Greece and Sweden. A WorldFish team at its site within the International Rice Research Institute, Philippines, is responsible for most of the inputting of data to FishBase and incorporation of new and improved features. FishBase is linked to GBIF, Genbank (presently for genetic information on 3,682 fish species), the IUCN Red List, SINGER, museum collections, and many other data sources, including fisheries statistics and surveys. The genetics content of FishBase itself is still somewhat limited. At present, it comprises cytogenetic (chromosome) data for 2,332 species, information on DNA markers for 2,548 species, and population genetics data from 233 species.[41]

FishBase is well placed to contribute to broadening and deepening coverage and accessibility of information on FiGR for their conservation and use. Broadening will require coverage of fish other than finfish, probably commencing with crustaceans, echinoderms and molluscs that are of economic importance in fisheries and aquaculture. This would assist the CGRFA for its future coverage of FiGR within agrobiodiversity, and would also significantly increase the general availability of free and authoritative information on fisheries and aquaculture genetics. Deepening will require expansion of the limited scope of coverage of finfish genetics in FishBase itself, as well as maintaining, and where necessary adding to, linkages

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[41] Fishbase genetics content, January 5, 2005. Source: Christine M.V. Casal, WordFish Center.

with other information sources in the highly dynamic subdisciplines of genetics, always avoiding unnecessary duplication of effort.

> **FiGR RECOMMENDATION 14:** The CGIAR should continue and expand its participation in FishBase, in order to contribute to wider coverage of and free access to information on FiGR. This expansion should include finfish and invertebrate genetic resources.

Others

There are many other existing and potential partners for the CGIAR in FiGR conservation. These include the Network of Aquaculture Centres in Asia-Pacific (NACA), the International Council for Exploration of the Sea, the Global Invasive Species Information Network, and the many prominent NGOs involved in FiGR conservation, fisheries and aquaculture; for example, Wetlands International (e.g. see Ticheler, 2000) and Aquaculture Without Frontiers (www.aquaculturewithoutfrontiers.org). In addition to the partnerships with national program and advanced research institutes, for example those between WorldFish and INGA members, fish and fisheries societies that have interests in conservation of FiGR are also potential CGIAR partners. For example, the American Fisheries Society is emphasizing responsible use of aquatic ecosystems in its strategic plan (Bireley et al., 2004), and is developing a Fisheries Conservation Foundation (Knuth and Clausen, 2005). There is also scope for more CGIAR partnerships with the private sector, as new public -private partnerships.

Many donors to the CGIAR have interests in conservation of FiGR, because these resources benefit poor farmers, poor fishers and poor fish consumers. Among these many donors, bilateral agencies and other organizations in Australia, Canada, the European Union (and within it, for example, France, Germany, the Netherlands, Italy and the United Kingdom), Japan, Norway, and the United States of America have been prominent past supporters of FiGR conservation. Support to conservation of aquatic life from foundations and trusts includes that from Pew Charitable Trusts of Philadelphia to the Seas Around Us project (www.saup.fisheries.ubc.ca) which, among a wealth of information and advice on conservation, provides access to a worldwide database of marine protected areas. Development banks are also raising the profile of conservation of aquatic biodiversity at ecosystem, species and genetic levels, as integral components of responsible fisheries management and aquaculture development, including establishment of aquatic protected areas and appraisal of the possible genetic impacts of enhanced fisheries (World Bank, 2004). This suggests that donor support should be available for expansion of the work of the CGIAR and its partners on conservation of FiGR, particularly if they emphasize this as a catalyst for increased responsibility in fisheries and aquaculture.

Postscript and acknowledgements

Conservation of FiGR is a huge and highly dynamic field. Keeping abreast of and fully understanding all of its technical and institutional developments are difficult and the author offers apologies for any errors and omissions here that may have arisen because of his shortcomings in this regard. Thanks are also offered to all friends and colleagues, too numerous to mention by name, who provided helpful information, especially those at the CBD Secretariat, FAO, FishBase, IPGRI, WorldFish and the World Fisheries Trust.

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List of Acronyms

ADB	Asian Development Bank
AfDB	African Development Bank
AI	Artificial Insemination
BAC	Bacterial Artificial Chromosome
BECA	BioSciences East and Central Africa
CBD	Convention on Biological Diversity
CCRF (the FAO's)	Code of Conduct for Responsible Fisheries
CD-ROM	Compact Disc - Read Only Memory
CGIAR	Consultative Group on International Agricultural Research
CGRFA	Commission on Genetic Resources for Food and Agriculture
CGS	Genome Consortium Cichlid
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CR	Critically Endangered (an IUCN Red List characterisation)
DAD-IS	Domestic Animal Diversity Information System
DAGRIS	Domestic Animal Genetic Resources Information System
DANIDA	Danish International Development Assistance
DART	Diversity Array Technology
DEGITA	Development of Genetically Improved Tilapia in Asia
EN	Endangered (an IUCN Red List characterisation)
ERFP	European Regional Focal Point on Animal Genetic Resources
EST	Expressed Sequence Tag
ET	Embryo Transfer
FAn	Farm animal
FAn1, FAn2, FAn3, ...	Reference to the individual recommendations for FAnGR
FanGR	Farm Animal Genetic Resources
FAO	Food and Agricultural Organisation (of the United Nations)
Fi	Fish
Fi1, Fi2, Fi3, ...	Reference to the individual recommendations for FiGR
FIGIS	Fisheries Global Information System
FiGR	Fish Genetic Resources
FishBase	A database of information about fish species
FTE	(Scientist) Full Time Equivalents
GBIF	Global Biodiversity Information Facility
GEF	Global Environment Facility
GIFT	Genetically Improved Farmed Tilapia
GIS	Geographical Information System
GMO	Genetically Modified Organism
GRPI	Genetic Resources Policy Institute
GTZ	Gesellschaft für Technische Zusammenarbeit
HTML	Hypertext Markup Language

ICARDA	International Centre for Research in Dry Areas
ICLARM	(the former) International Centre for Living Aquatic Resources Management (now the WorldFish Centre)
ILCA	(the former) International Livestock Centre for Africa (now part of ILRI)
IFPRI	International Food Policy Research Institute
INGA	International Network for Genetics in Aquaculture
ILRAD	(the former) International Laboratory for Research on Animal Diseases (now part of ILRI)
ILRI	International Livestock Research Institute
IPGRI	International Plant Genetic Resources Institute
ISAG	International Society of Animal Genetics
IUCN	The World Conservation Union
IWMI	International Water Management Institute
MODAD	Measurement of Domestic Animal Diversity
NACA	Network of Aquaculture Centres in Asia
NGO	Nongovernmental Organisation
NIH	National Institutes of Health
O1, O2, O3, ...	Reference to the numbers of joint (or overall) recommendations of the two reports
PGR	Plant Genetic Resources
PRC	People's Republic of China
R&D	Research and Development
SADC	Southern Africa Development Cooperation
SC	the CGIAR Science Council
SGRP	Systemwide Genetic Resources Program
SINGER	Systemwide Information Network on Genetic Resources
SLU	Swedish Livestock University
SOW	State of the World – review of FanGR organised by the FAO
UNCLOS	United Nations Convention on the Law of the Sea
UNDP	United Nations Development Programme
VU	Vulnerable (an IUCN Red List characterisation)
WFT	World Fisheries Trust
WorldFish	CGIAR Center concerned with research on fish and living aquatic resources

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