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منظمة الأغذية والزراعة للأمم المتحدة

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Food and Agriculture Organization of the United Nations

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Item 3 of the Draft Provisional Agenda

INTERNATIONAL TECHNICAL CONFERENCE ON ANIMAL GENETIC RESOURCES FOR FOOD AND AGRICULTURE

Interlaken, Switzerland, 3 – 7 September 2007

Scientific Forum on Animal Genetic Resources

Page

SCIENTIFIC FORUM ON ANIMAL GENETIC RESOURCES

Kasino Kursaal, Interlaken
3 September 2007, 10:30 – 18:00

Introduction

1. The Scientific Forum is intended to be an informal occasion at which some of the key scientific challenges in the management of animal genetic resources can be discussed in depth, before the formal proceedings of the Conference begin.

2. Four papers have therefore been prepared by teams of leading experts in their field to highlight recent scientific developments in each of the main themes dealt with in Part 4 (the state of the art in the management of animal genetic resources) of *The State of the World's Animal Genetic Resources for Food and Agriculture*:

- The dynamics of livestock production systems, the drivers of change,
- Inventory, characterization and monitoring,
- Sustainable use and genetic improvement,
- Conservation of animal genetic resources.

3. Each of these papers will be presented by one of the authors. This will be followed by a panel discussion, in which a representative range of stakeholders has been invited. Questions and comments from the participants in the meeting are then welcomed.

4. The Scientific Forum will end with an open discussion on how the wider society can be involved in the implementation of the *Global Plan of Action*, and in research for development.

5. The Scientific Forum will be interpreted. In order not to waste interpretation time, participants are requested to please be on time.

PROGRAMME AND TIME-TABLE

Aims and expected outcomes of the Scientific Forum

10:30 – 10:45	Introduction by the Chairman of the Forum, Mr Fritz Schneider, Swiss College of Agriculture

Dynamics of animal production systems and animal genetic resources: drivers of change and prospects for animal genetic resources

Carlos Sere, Akke van der Zijpp and Ed O. Rege

10:45 – 11:05	Presentation by Mr Carlos Sere, International Livestock Research Institute (ILRI), Kenya
11:05 – 11:40	Panel discussion: • Mr Ken Laughin, European Forum of Farm Animal Breeders (EFFAB), The Netherlands • Mr Fernando Madeleña, School of Veterinary Sciences, Federal University of Minas Gerais, Brazil • Ms Ilse Koehler Rollefson, League for Pastoral Peoples and Endogenous Livestock Development, Germany/India • to be announced
11:40 – 12:15	Open discussion: interventions from the floor

Inventory, characterization and monitoring

Michèle Tixier-Boichard, Workneh Ayalew and Han Jianlin

12:15 – 12:35	Presentation by Ms Michèle Tixier-Boichard, Institut National de la Recherche Agronomique (INRA), France
12:35 – 12:55	Panel discussion: • Mr Richard Clarke, Rare Breeds Survival Trust (RBST), United Kingdom • to be announced • to be announced
12:55 – 13:15	Open discussion: interventions from the floor

13:15 –13:30	Summary by the Chairman of the morning’s discussions

13:30 – 15:00	**Lunch Break**

Sustainable use and genetic improvement

Chanda Nimbkar, John Gibson, Mwai Okeyo and Paul Boettcher

15:00 – 15:20	Presentation by Ms Chanda Nimbkar, Nimbkar Agricultural Research Institute (NARI), India
15:20 – 15:40	Panel discussion: • Mr Jan Philipsson, Interbull Centre, Sweden • Mr Raoul Perezgrovas, Instituto de Estudios Indígenas, Chiapas, Mexico • Ms Xuan Li, South Centre, Switzerland
15:40 – 16:00	Open discussion: interventions from the floor

Conservation of animal genetic resources: approaches and technologies for *in situ* and *ex situ* conservation

John A. Woolliams, Oswald Matika and James Pattison

16:00 – 16:20	Presentation by Mr John Woolliams, Roslin Institute, United Kingdom
16:20 – 16:40	Panel discussion: • Mr Arthur Mariante, EMBRAPA Genetic Resources and Biotechnology, Brazil • Ms Nityia Ghotge, ANTHRA, India • Mr Jean Boyazoglu, Rare Breeds International, France
16:40 – 17:00	Open discussion: interventions from the floor

Animal science meets society

How can the wider society be involved in the implementation of the *Global Plan of Action*, and in research for development?

17:00 – 17:10	What have we learned from today's discussions? • Introduction by the Chairman
17:10 – 17:35	Interventions from the panellists
17:35 – 18:00	Open discussion: interventions from the floor

DYNAMICS OF LIVESTOCK PRODUCTION SYSTEMS, DRIVERS OF CHANGE AND PROSPECTS FOR ANIMAL GENETIC RESOURCES

Carlos Sere[1], Akke van der Zijpp[2], Gabrielle Persley[1] and Ed Rege[1]*

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Summary

This overview analyses the key drivers of change in the global livestock sector and assesses how they are influencing current trends and future prospects in the world's diverse livestock production systems and market chains; and what are their consequent impacts on the management of animal genetic resources for food and agriculture. The trends are occurring in both developing and industrialized countries, but the responses are different. In the developing world, the trends are affecting the ability of livestock to contribute to improving livelihoods and reducing poverty as well as the use of natural resources. In the industrialized world, the narrowing animal genetic resource base in industrial livestock production systems raises the need to maintain a broader range of animal genetic resources to be able to deal with future uncertainties, such as climate change and zoonotic diseases. This chapter discusses:

What are the global drivers of change for livestock systems? – Economic development and globalization; changing market demands and the "livestock revolution"; environmental impacts including climate change; and science and technology trends;

How are the livestock production systems responding to the global drivers of change? – Trends in the three main livestock production systems (industrial, crop-livestock and pastoral systems); the range and rate of changes occurring in different systems and how these affect animal genetic resources. The implications are that breeds cannot adapt in time to meet new circumstances. Hence new strategies and interventions are necessary to improve the management of animal genetic resources in situations where these genetic resources are most at risk.

What are the implications for animal genetic resources diversity and for future prospects of their use?
Industrial livestock production systems are expected to have a limited demand for biodiversity, while crop-livestock and pastoral systems will rely on biodiversity to produce genotypes of improved productivity under changing environmental and socio-economic conditions. All systems will rely on biodiversity, albeit to varying degrees, to cope with expected climate change.

What immediate steps are possible to improve animal genetic resources characterization, use and conservation?
Appropriate institutional and policy frameworks are required to improve animal genetic resources management and these issues are being addressed at national and intergovernmental levels, in a process led by FAO to promote greater international collaboration on animal genetic resources. Based on an analysis of the current situation, the continuing loss of indigenous breeds and new developments in science and technology, there are several complementary actions that can begin to improve the management of animal genetic resources and maintain future options in an uncertain world. These are summarized here as:

[*] This paper has benefited from inputs from several reviewers and other contributors, and we thank all for their thoughtful insights. We acknowledge the contributions of our colleagues at FAO, particularly Irene Hoffmann, Dafydd Pilling and Henning Steinfeld, and at the International Livestock Research Institute (ILRI): Ade Freeman, Mario Herrero, Olivier Hanotte, Steve Kemp, Sandy McClintock, Sara McClintock, Margaret MacDonald-Levy, Susan MacMillan, Grace Ndungu, An Notenbaert, Mwai Okeyo and Robin Reid.

(1) "Keep it on the hoof" – Encouraging the continuing sustainable use of traditional breeds and *in situ* conservation by providing market-driven incentives, public policy and other support to enable livestock keepers to maintain genetic diversity in their livestock populations.

(2) "Move it or lose it" – Enabling access to and the safe movement of animal genetic resources within and between countries, regions and continents is a key factor in use, development and conservation of animal genetic resources globally.

(3) *"Match breeds to environments"* – Understanding the match between livestock populations, breeds and genes with the physical, biological and economic landscape. This *"landscape livestock genomics"* approach offers the means to predict the genotypes most appropriate to a given environment and, in the longer term, to understand the genetic basis of adaptation of the genotype to the environment.

(4) "*Put some in the bank"* –- New technologies make *ex situ, in vitro* conservation of animal genetic resources feasible for critical situations and are a way to provide long-term insurance against future shocks.

The multiple values, functions and consequences of livestock production systems and their rapid rate of change lead to divergent interests within and between countries. Conversely, the uncertainty about the implications of rapid, multifaceted global change for each livestock production system and the resulting future changes in the required genetic make-up of animal genetic resources make collective action to tackle conservation of animal genetic resources a long-term, global public good. Conserving animal genetic resources will not by itself solve these problems, but it is an important first step towards maintaining future options.

Advances in science and the technology, in areas such as reproductive technology, genomics and spatial analysis, as well as progress in conceptualization of global public good production for the future management of animal genetic resources, should enable the international community to address both the short- and long-term challenges in innovative ways.

1. INTRODUCTION

This overview paper analyses the key drivers of change in the global livestock sector and assesses how they are influencing current trends and future prospects in the world's diverse livestock production systems and market chains; and what are their consequent impacts on the management of animal genetic resources for food and agriculture. The trends are occurring in both developing and industrialized countries, but the responses are different. In the developing world, the trends are affecting the ability of livestock to contribute to improving livelihoods and reducing poverty as well as the use of natural resources. In the industrialized world, the narrowing animal genetic resource base in industrial livestock production systems raises the need to maintain a broader range of animal genetic resources to be able to deal with future uncertainties, such as climate change and zoonotic diseases.

The range of livestock covered here are domesticated species, particularly the five major economic species (cattle, sheep, goats, chickens and pigs). There are no detailed figures yet to link specific breeds with specific production systems. We are tackling the problems from a production system angle. Throughout the paper, and based on the findings of *The State of the World's Animal Genetic Resources for Food and Agriculture*, we use the approximation that commercial breeds, as a subgroup of international transboundary breeds, are used in intensive, high-external input livestock production systems (termed "industrial systems"), and that local breeds are the basis in most extensive and low-external input systems. These are called here "pastoral systems" and "crop-livestock systems", respectively. This paper covers four main areas:

- What are the global drivers of change for livestock systems?
- How are the three main livestock production systems (industrial, crop-livestock and pastoral systems) responding to the global drivers of change, and what are the implications of the range and rate of changes for the management of animal genetic resources in these systems?
- What are the implications for animal genetic resources diversity and future prospects of their use?
- What immediate steps are possible to improve animal genetic resources characterization, use and conservation?

2. DRIVERS OF CHANGE IN GLOBAL LIVESTOCK SYSTEMS

2.1 Economic development and globalization

Livestock production is a complex and heterogeneous part of global agriculture. It ranges from highly automated, intensive large-scale production of pigs and poultry and, to a lesser degree, cattle, to small-scale, largely scavenging production of backyard pigs and chicken. Domestication of livestock started several millennia ago and humans have shaped the genetic make-up of domesticated animals to respond to human needs in different production environments.

This genetic make-up of livestock that resulted from this long-term process has been put under stress by fast-paced changes over the past few decades, across the entire range of biophysical, social and economic contexts in which humans keep animals. These changes can be subsumed under terms of economic development and globalization. These are themselves largely driven by technical progress, plus the global exchange of knowledge and products. These trends are also characterized by unequal access to natural resources, financing, markets, technology and personal mobility.

Since 1945, the world has seen an unprecedented economic growth, starting in the industrialized economies (countries of the Organisation for Economic Co-operation and Development [OECD]) and expanding into the rest of the world over the past two decades. The latter is epitomized by the economic growth path of China. A number of developing countries, mainly in Asia and Latin America, have undergone major transformations associated with significant growth in their economies and increases in per capita incomes.

The socio-economic indicators for selected countries are given in Table 1. The following inferences can be drawn from the data:

- The contribution of livestock to agricultural gross domestic product (GDP) (column 2) demonstrates the significance of the livestock sector in many economies (providing value addition); this occurs even in countries that are experiencing rapid economic growth (India and China) and/or have a growing share of industrial livestock systems (China, Brazil and Argentina).
- The key demand drivers of GDP growth and urbanization (columns 2 and 3) point towards growing demand for livestock products across all regions in the developing world. This “livestock revolution” is discussed further below.
- The trends in foreign direct investment (FDI) (column 4) show that increases in FDI are concentrated in a few countries (China and India). These countries are ones in which the industrialization of livestock production has been rising sharply. Some other countries in Africa (e.g. Kenya and Botswana) have also recorded significant increases in FDI over the past decade, although from a lower base.

Economic development has led to important changes in the spatial distribution of the world’s population, leading to a rapid process of urbanization in the developing world. At the same time, breakthroughs in medical research and their applications have led to dramatic increases of the human population in developing countries. In the industrialized world, population growth rates have declined in the last decades as social security, female employment in labour-scarce economies and cultural/social changes have led to declining birth rates and gradually aging populations. In terms of consumer demand, there is more demand for “fast food” and processed animal products. Food safety requirements are becoming increasingly stringent, due to disease problems such as bovine spongiform encephalopathy (BSE) associated with processed animal products. A similar trend is occurring in developing countries, although currently limited to the affluent urban class.

Another key driver of change that is leading towards larger-scale, cereal-based animal production systems around the world has been the rise in labour costs in the industrialized economies and in some parts of the developing world, as a result of economic growth and rising incomes.

Changing economic policy associated with rapid economic growth in parts of the developing world (e.g. Asian “tiger” economies) has changed the investment climate in emerging economies and led to massive inflows of FDI. Similarly, labour migration from developing to industrialized economies has generated capital flows back to developing countries, which are often larger than official development assistance. Capital investments from outside the farming community, for example in the feed industry and livestock production chains in Southeast Asia, are also influencing changes in livestock production systems.

The effects of globalization and growing incomes have by no means been evenly distributed within or between countries. In the context of rapid population growth, many countries and social and ethnic groups within countries have not participated in the growth process. Large numbers of poor people, particularly in rural areas, have been left behind or adversely affected by the changes. For example, such communities may actually suffer from loss of access to natural resources, bear the brunt of environmental impacts and be characterized by the breakdown of traditional social and economic ties and values, without a better (or at least viable) alternative. Also, local breeds of animals are often not competitive in this changing world.

These inequalities pose a major challenge for the global community, which has responded by setting the Millennium Development Goals (MDGs), a UN-driven process to address several core problems facing the world. The MDGs include a commitment to halve the numbers of people living in poverty by 2015, as well as setting several other key development targets, including protecting the environment and conserving biodiversity. The sustainable use and conservation of the world’s animal genetic resources for food and agriculture supports the Millennium Development Goals 1 and 7, and is also covered by the Convention on Biological Diversity (CBD).

Table 1: Socio-economic indicators for selected countries

	Contribution of livestock to agricultural GDP (%)		GDP growth (annual change) [a] (%)				Urban population[b]			FDI[c]		
							Total population (%)		Average annual growth (%)	Annual average in US$ million		
	1990–1995 average	2000–2005 average	1990	1995	2000	2005	1990	2004	1990–2004	1997–1999	2000–2002	2003–2005
Sub-Saharan Africa												
Botswana	85.0	82.1	6.8	4.5	8.3	6.2	42	52	3	77	161	363
Kenya	42.5	44.5	4.1	4.3	0.6	5.8	25	40	6.1	15	48	50
South Africa	46.1	44.0	–0.3	3.1	4.2	5.1	49	57	3	1 955	2 991	2 581
Latin America and Caribbean												
Argentina	45.9	36.5	–1.3	-2.8	-0.8	9.2	87	90	1.4	13 480	4 911	3 552
Brazil	41.8	44.4	–4.2	4.2	4.3	2.9	75	84	2.3	26 713	23 942	14 501
Peru	36.0	33.1	–5.1	8.6	3	6.4	69	74	2.2	1 908	1 370	1 890
East Asia and Pacific												
Cambodia	20.5	20.1	1.1	6.5	8.4	13.4	13	19	5.5	226	148	198
China	26.9	24.6	3.8	10.9	8.4	10.4	27	40	3.6	42 247	43 983	60 380
Viet Nam	16.7	18.0	5	9.5	6.8	8.4	20	26	3.4	1 768	1 333	1 671
South Asia												
India	26.51	30.75	6	7.6	5.3	9.2	26	29	2.5	2 794	4 894	5 552
Pakistan	49.1	53.5	4.5	5	4.3	8	31	34	3.3	585	505	

Sources:

a. IMF, 2007

b. World Bank, 2006

c. United Nations, 2007

2.2 Market demand for livestock products – the "livestock revolution"

Growing demand for animal products – as well as higher standards to improve the quality and safety of the products – and more processed animal products have substantial consequences for the evolution of livestock production systems. Overall, the processes of economic development, population growth, urbanization and changing patterns of consumption have led to a dramatic increase in the consumption of animal products in the developing world, a process that has been termed the *"livestock revolution"*. FAO data suggest that this trend is expected to continue for several decades because of the strong direct correlation between rising income and increasing animal product consumption.

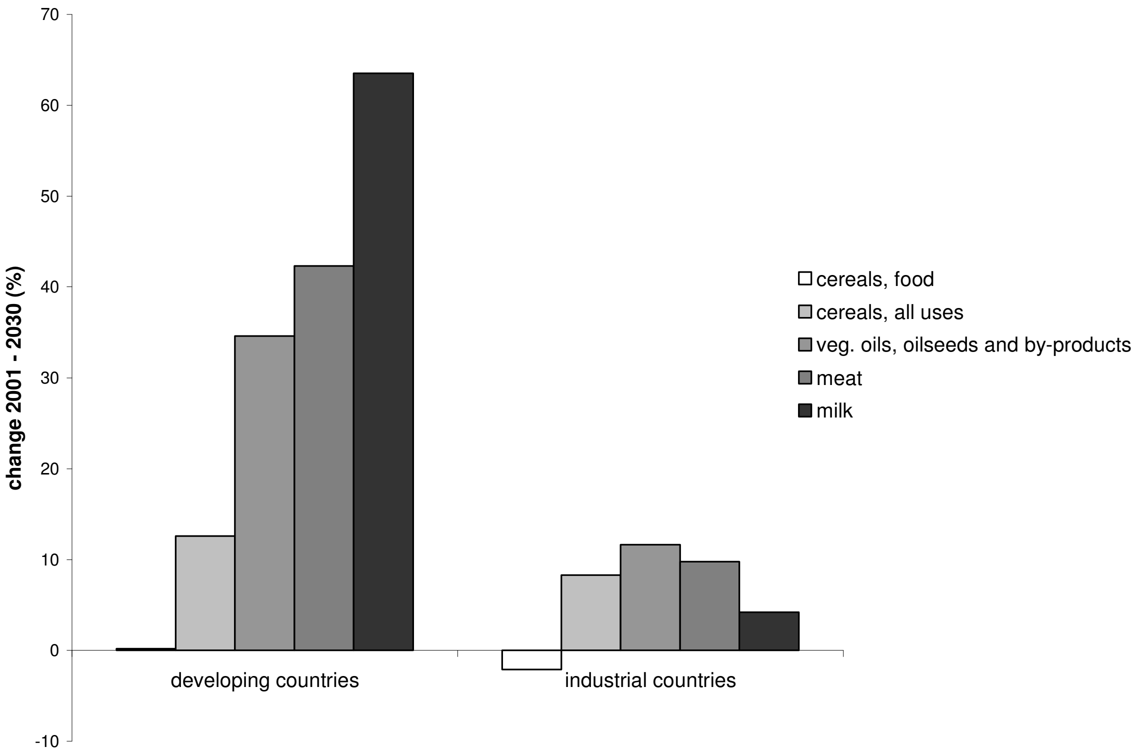
Figure 1 shows the expected percentage changes in per capita consumption of selected food commodities in developing and industrialized countries between 2001 and 2030, providing evidence of the "livestock revolution" occurring in the developing world. There are large differences between the projected per capita growth rates in consumption of livestock products (meat and milk) between developing and industrialized countries. There are also marked differences in the per capita growth rates of the different products in developing countries, with meat and milk being the highest, followed by oil seeds. Growth rates for cereal consumption as human food are stagnating everywhere, but increasing for other uses, especially for animal feed and biofuels.

The consumption of milk and meat per capita are shown in Figures 2 and 3 respectively. These data illustrate substantial differences in current consumption of meat and milk between industrialized and developing countries; the rates of growth in consumption are higher in the developing world. This trend is part of the "livestock revolution" and is the result of increased demand and increased incomes, economic growth and urbanization in developing countries. Consumption per capita of milk and meat is currently between two and four times higher in industrialized countries than in the developing world but, in absolute terms, demand is higher in the developing world.

The growing demand for animal products in the developing world is associated with the changes in production location, facilitated by the increasing ease of transporting feed and animal products around the world. Animal products were previously produced close to where the consumers live. Increasingly, livestock production now takes place close to the locations with good access to feed, either in feed production areas or ports. The animal products are then transported to markets. This trend is changing the competitiveness of diverse livestock production systems worldwide, with more animal products being produced in lower cost economies (mainly in industrial and crop-livestock systems) and traded in domestic, regional and international markets.

At the same time, large numbers of poor people depend on livestock production for their livelihoods and, for some of them, livestock offer a pathway out of poverty. These smallholders and pastoralists frequently compete for markets with the commercial sector, which is producing animal products in industrial systems worldwide. Smallholders and pastoralists together with their traditional breeds are increasingly being pushed out by the industrial systems coming into the developing world. Hence there is pressure for smallholders and pastoralists to replace their traditional breeds with more productive but less resilient breeds in order to be able to compete in the expanding livestock markets in the developing world.

Figure 1. Expected percentage changes in per capita consumption of selected food commodities in developing and industrialized countries, 2001–2030

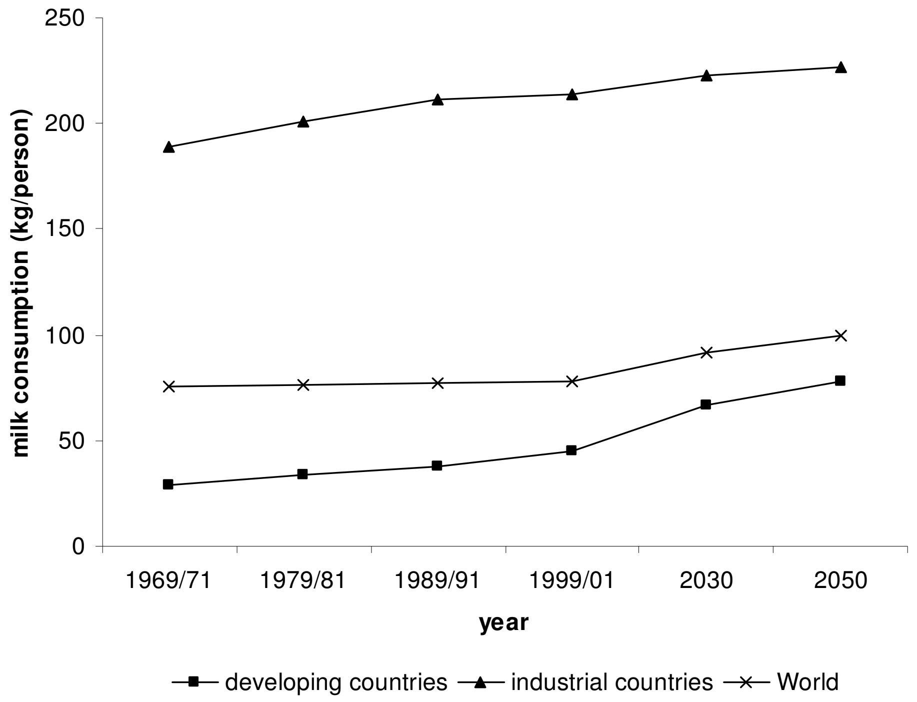


Source: adapted from IAASTD, 2007.

Technological developments associated with international transport, partially related to the increased access to capital and the opening of many economies, have dramatically increased the role of international trade in animal products. The expansion of international trade in animal products has brought to the fore the need to establish more stringent animal health and food safety standards, in order to manage the risks to the domestic sector of individual countries and to protect consumers. These health and food safety requirements have been driven by the growing problems of animal diseases, including zoonoses. These disease risks are linked to a number of factors including increasing stock numbers, the intimate cohabitation of poor families with their animals and the increased global movement of animals and animal products.

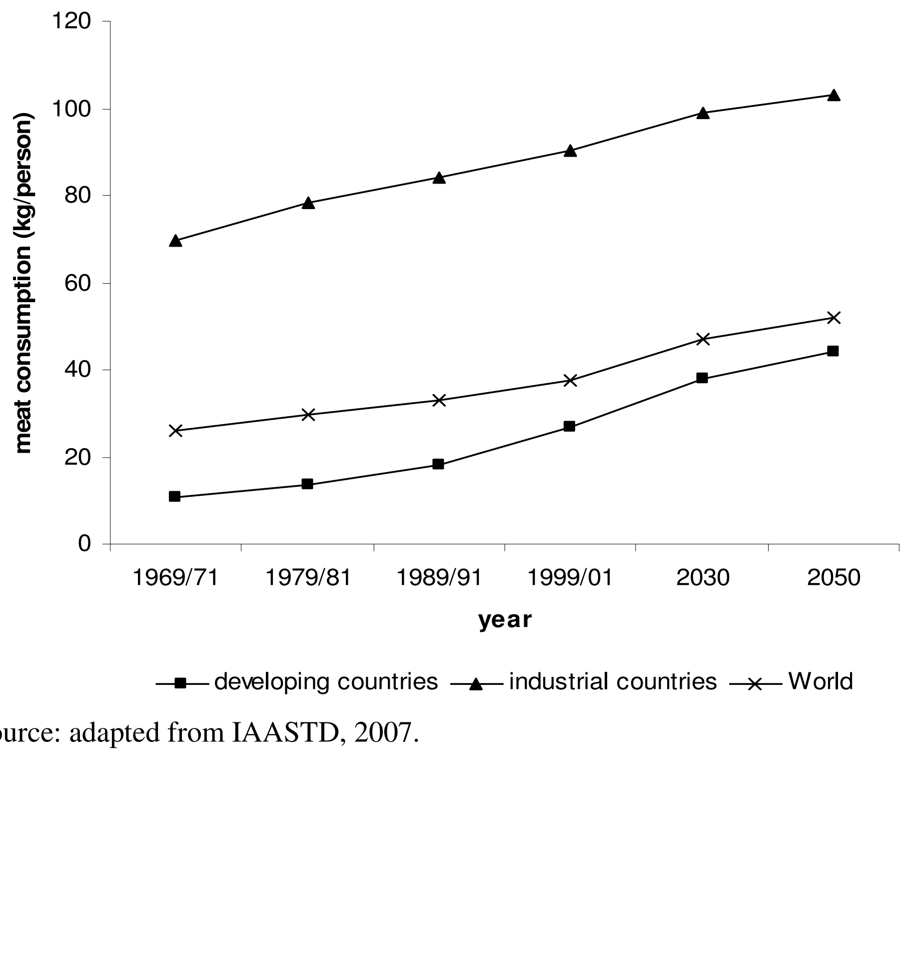
Domestic markets, including the informal livestock product markets, handle the largest share of the livestock products consumed in developing countries. However, in urban areas, the modern food retail sector is also growing rapidly, and imposing specific requirements in terms of quality assurance and homogeneity of the products (of national and international origin). The term "supermarket revolution" has been coined for these processes. These two marketing systems require markedly different food safety and biosecurity standards, affecting livestock production systems supplying these markets.

Figure 2. Milk consumption per capita to 2050 (kg/person)



Source: adapted from IAASTD, 2007.

Figure 3. Meat consumption per capita to 2050 (kg/person)



Source: adapted from IAASTD, 2007.

Table 2 shows that the share of supermarkets in food retailing has been increasing over the past two decades in much of the developing world. If current trends in expanding urban populations continue, the share of supermarkets in the urban food retail sector in the developing world will increase to levels that they are now in the industrialized economies (i.e. about 80 percent of the total food retail sector). The changing set of actors implied by the supermarket revolution and the growing importance of agribusiness in food retailing will have important implications for poor farmers.

The coexistence of three markets for animal products in the developing world (the traditional, frequently informal markets, the growing formal (super)markets for the urban middle classes and the regional/international export markets) poses particularly daunting challenges for policy-makers in pursuing mutually compatible policies of: (1) protecting livelihoods among the smallholder livestock keepers and pastoralists; (2) supporting efficient markets for the urban population; and (3) encouraging active engagement of livestock producers and their traditional breeds in the regional and global livestock markets.

Table 2: Trends in share of supermarkets in total food retail for selected countries

Waves of diffusion and average market share	Country	Year	Supermarket share in food retail (%)
Industrialized countries e.g.	USA	2005	80
First wave of developing countries (10–20% market share around 1990)	Argentina	2002	60
	Brazil	2002	75
	Taiwan Province of China	2003	55
	Czech Republic	2003	55
	Costa Rica	2001	50
	Chile	2001	50
	Republic of Korea	2003	50
	Philippines	2003	50
	Thailand	2003	50
	South Africa	2001	55
Second wave of developing countries (5–10% market share around 1990)	Mexico	2003	56
	Ecuador	2003	40
	Columbia	2003	47
	Guatemala	2002	36
	Indonesia	2001	30
Third wave of developing countries (Virtually zero market share around 1990)	Bulgaria	2003	25
	Kenya*	2004	20
	Nicaragua	2006	20
	China*	2004	30
	India	2007	9

*share of urban food retail
Source: Reardon, Henson and Berdegué, 2007.

The livestock product markets in industrialized countries are evolving along quite different paths. Besides consuming relatively inexpensive livestock products from large-scale industrial systems, there is increasing demand for niche products, frequently linked with certification of origin, often produced in traditional ways or with specific breeds, by "organic agriculture", and/or with particular concern for animal welfare.

Animal welfare is an increasing area of concern, especially in markets in industrialized countries. These concerns include caring for animals in all types of production systems. There is particular criticism of intensive housing systems for animals (e.g. chickens, pigs, dairy cows). This is leading to more animal friendly housing systems such as group housing of sows; and free range hens as alternatives for the caging for laying hens. Some consumers in industrialized countries are prepared to pay a premium for animal products coming from such production systems that take account of animal welfare concerns. Animal welfare concerns are highly culture-specific and, while important in some societies, others consider them to be non-tariff trade barriers. Some of these trends will dictate breeds and breeding practices – for example, performance under range conditions and "broodiness" of hens will be important attributes for the niche markets.

In the industrialized countries, hobby farming has become a popular activity, using relatively small land areas for limited numbers of livestock such as sheep, goats, horses and cattle. For *in situ* conservation of species and breeds within species, these part-time farmers are important contributors.

2.3 Environmental effects of livestock production

The rapid population growth and the growing consumption of goods and services by people whose incomes are growing puts pressure on natural resources and the environment. Livestock production, under certain conditions, is driving degradation processes and is at the same time affected by them. Increasing land use for food crops and crops for biofuels is increasing the pressure on rangelands and other open access or community managed resources. This affects the viability of the low-input production systems, the sustainable use of traditional breeds and thus the livelihoods of pastoralists and smallholders.

At the same time, the rapid growth of large-scale, intensive animal production units puts a serious constraint on the capacity of the environment to deal with carbon dioxide and methane output, nutrient loading in certain areas, effluent into rivers and seas, loss of biodiversity because of land clearing to grow feeds (for example, soybeans in Latin America) and other environmental impacts.

The recent FAO (2006) report *Livestock's long shadow: environmental issues and options* focused on the effects of livestock on the environment. The "long shadow" refers to the negative effects of the livestock food chain on almost all aspects of the environment; livestock production is associated with carbon dioxide, methane and nitrous oxide emissions, water depletion, soil erosion, soil fertility, damage to plants, loss of biodiversity and competition with wildlife.

As population and living standards grow, natural resources become a limiting factor. Particularly in marginal zones for rangeland-based animal production (pastoral systems), alternative land uses such as provision of opportunities for carbon sequestration through trees or wildlife conservation may become increasingly competitive with livestock production. On the other hand, livestock production in pastoral systems can be complementary to other services – for example, livestock production provides a means to maintain shrub/rangeland systems, with grazing reducing the risk of fire in extensive rangelands and providing other ecological services.

Climate change effects

The relationship between livestock production and climate change works in both directions. On the one hand, livestock contributes significantly to climate change via carbon dioxide, methane and nitrous oxide production (calculated in FAO (2006) at 18 percent of the total global greenhouse gas emissions from human sources). On the other hand, climate change will have important effects on farming systems and on the role of livestock, both directly and indirectly.

For example, large parts of Africa and Central Asia are likely to experience reductions in the length of growing period as a result of increased temperatures and lower rainfall. This is likely to lead to lower crop yields and reduced rangeland productivity, thus affecting the provision of feeds for animals. Climate change is also likely to change the distribution of animal diseases and their vectors. Large parts of South and Southeast Asia are likely to experience increases in rainfall and in the number of extreme climatic events (e.g. cyclones). This could lead to increased exposure of livestock to diseases, such as those caused by helminthes. Crop losses due to extremes in climate could result in less animal feed being available, especially in crop-livestock and pastoral systems.

2.4 Science and technology drivers of change: general aspects and in relation to animal breeding and genetics

Science and technology have had a major influence on the transformation of animal production in industrialized economies and increasingly in developing countries. With increasing labour scarcity, larger, high-output and more productive animals were bred. From multipurpose breeds, highly specialized breeds were developed. Generally, disease resistance was sacrificed for higher output, taking into account that through capital investments it became possible to adapt the environment to the existing animals in ways that had not been possible in the past. Research into housing and mechanization allowed significant labour productivity increases. These advances occurred in many species but particularly in short-cycled monogastric species such as poultry and pigs.

Animal nutrition research, linked with breeding, has made major contributions to improving feed efficiency and shortening production cycles and thereby reducing maintenance feed requirements and allowing a more efficient use of the capital investments and natural resources.

In the developing world, the impact of modern livestock science and technology has been uneven. Industrial livestock production systems (mainly for chickens) with limited links to the local resource base have been developed in some locations close to urban demand and/or to ports, given their frequent dependence on imported feed. Smallholder crop-livestock systems are much more reliant on locally available feed and traditional breeds. These crop-livestock systems are highly complex, delivering multiple products and services. Progress in improving the sustainable productivity of these systems has been much more limited and is a significant research challenge. System-based research is required to help these systems change in line with the changing social, economic and environmental context in which they operate. Currently, the speed of change of animal production systems and market chains is very high in some locations/regions, and is accompanied by loss of animal genetic resources. (This is discussed further below.)

Science and the management of animal genetic resources

The science related to the management of animal genetic resources has made significant progress, based mainly on advances in molecular biology and genetics as well as new developments in information and communications technology (ICT). The main advances are summarized in this paper and are discussed in more detail in the following papers. The advances include:

- Technologies are increasingly available for **characterizing** animal genetic resources

Molecular characterization is providing a better understanding of the genetic diversity in global livestock populations. Functional genomics is also making it possible for genomes to be characterized, specific genomic regions and genes identified and gene functions elucidated. These technologies are based on a combination of genetic analysis and bioinformatics.

- New technologies are becoming increasingly available for **utilizing** animal genetic resources better, to meet changing needs, threats and opportunities

New genetic technologies enable the better characterization of breeds and populations. Other technologies, such as geographic information systems (GIS), enable the better characterization of the environment. Linking this knowledge will enable making a better fit between a genotype and an environment and, in the longer term, understanding the genetic basis of genotype x environment interaction. In this way, we can begin to identify appropriate genotypes for fast-changing environments. For example, there are increasing threats from drier climates that increase the need for hardier animals, tolerant to drought and disease. Animal reproduction technologies such as sexed semen and *in vitro* fertilization of embryos will enable the rapid development of new populations and faster distribution of superior animal genetics. These technologies are not yet widely used in developing countries, but offer future options in areas where a genetic solution is possible.

- Technologies are increasingly available for **conserving** animal genetic resources

New technologies are available for improved cryopreservation of embryos and semen that are applicable in more species. These technologies lead to new options for *ex situ, in vitro* conservation of animal genetic resources. For example, use of testes and ovaries obtained from livestock as sources of frozen semen and *in vitro* fertilization (IVF) embryos for long-term cryopreservation of animal genetic resources in gene banks.

- ICTs enable more precise linkage of genotypes and locations/production environments

New developments in ICTs also have implications for animal genetic resources characterization and conservation. These developments are linked to improvement of infrastructure and communication systems, such as the widespread use of mobile phones. ICTs also allow georeferencing to link particular genotypes with specific geographic locations. This knowledge provides the scientific underpinning of *in situ* conservation practices.

In order to take full advantage of the opportunities presented by advances in ICT, it is necessary to develop common standards for characterizing animal genetic resources, in terms of their genetics, phenotype and production system, so that knowledge can be shared among different communities and countries. Given such systematic and standardized descriptions of livestock, the intersection between new ICTs and modern genetics, through genomics and bioinformatics, presents opportunities to examine genome function by integration of these rich data sets.

3. CURRENT STATUS AND TRENDS IN LIVESTOCK PRODUCTION SYSTEMS

In the light of the above drivers of change, this section discusses:

- the relative importance of the three main livestock systems worldwide (industrial, crop-livestock and pastoral) and the breeds they harbour;
- the implications of global drivers of change for the different livestock production systems;
- the implications for livelihoods
- the implications of the scope and rate of changes in the main livestock production systems for current and future animal genetic resources management

3.1 Livestock species by region

The geographic distribution of the major livestock species worldwide is given in Table 3. This table shows that for all species the majority of animals are in the developing world. It also shows the importance of different species by region. For example, ruminants are most important in sub-Saharan Africa (SSA) and Latin America (LAC), both continents with vast areas of savannah and relatively low population densities. Poultry is most important in East Asia and the Pacific and LAC, regions of either high economic growth or with middle-income countries with high degrees of urbanization and adequate market infrastructure.

3.2 Livestock production systems by region

Three major types of livestock production systems can be identified worldwide – industrial livestock systems (IS); crop/livestock systems, mainly in high potential areas (CLS); and pastoral systems, mainly in marginal areas (PS).

Table 3: Geographic distribution of livestock (millions of heads)

	Cattle	Sheep and goats	Pigs	Poultry
Sub-Saharan Africa[a]	219	365	22	865
Near East and North Africa[a]	23	205	0	868
Latin America and Caribbean[a]	370	112	70	2 343
North America[a]	110	10	74	2 107
East Europe and Central Asia[a]	84	121	72	1 ,160
West Europe[a]	83	119	125	1 072
East Asia and Pacific[a]	184	514	543	7 168
South Asia[a]	244	303	15	777
Industrial world[b]	318	390	284	4 663
Developing world[b]	1 ,046	1,460	659	12 735

Source*:* FAOSTAT, 2007.
Notes*:* a. average 2000–2005 number; b. reported number for 2004

The share of livestock in each of these systems in different geographic regions is shown in Table 4. These data show that most livestock are located in crop-livestock systems. The proportion of livestock in industrial systems by region is mainly a function of economic status and rate of growth (e.g. higher proportions of industrial systems in the industrialized world and Asia).

Table 4: Share of livestock (total livestock units [TLU]: cattle, goats, sheep, pigs and poultry) per livestock production system for selected regions and countries

	TLU shares (%)		
	Livestock production system		
	PS	CLS	IS
Sub-Saharan Africa			
Botswana	80	19	0.14
Kenya	34	50	14
Mali	47	51	0.9
South Africa	55	36	8
Latin America and Caribbean			
Argentina	42	40	16
Brazil	18	63	17
Peru	44	21	33
East Asia and Pacific			
Cambodia	6	73	20
China	9	70	19
Viet Nam	0.75	82	16
South Asia			
India	2	82	15
Pakistan	25	63	10
Developed World			
European Union	9	67	22
Russian Federation	16	50	32

Source: FAO, 2004.

3.3 Implications of global drivers of change for livestock production systems

Current status of livestock production systems

Each of the three main livestock production systems responds differently to the effects of the global drivers of change, and therefore has different development and investment needs. The overarching trends are increasing intensification in both industrial systems and in crop-livestock systems in order to meet increasing demand for animal products and consumer preferences for higher-quality products that meet stringent food safety standards.

- Intensification and scaling up trends in industrial and crop-livestock production systems

The demand for livestock products has been met by intensification of livestock production systems in both developing and industrialized countries. Among other factors, this intensification has been based on using cereal grains as livestock feed. For example, in OECD countries, livestock feeding in intensive systems accounts for two-thirds of the average per capita grain consumption. In contrast, crop-livestock systems in sub-Saharan Africa and India use less than 10 percent of grains as feeds as they rely mostly on crop-residues (40–70 percent of feed), grazing and planted fodders.

- Market characteristics and demand

The trend towards intensification of industrial systems and crop-livestock systems is largely driven by consumer demands for livestock products, both fresh and processed. The market characteristics are increasing demand for animal products in developing countries, plus quality preferences and food safety requirements in all markets. Public–private partnerships that provide services and market opportunities also play a key role in intensifying industrial and crop-livestock systems.

Future trends in livestock production systems

Intensive systems. Intensive systems are facing increasing restrictions, owing to their associated negative environmental effects, such as problems of waste disposal and water contamination. Demand for cereals is also increasing for other purposes (e.g. biofuels) and this is driving up the price of cereals, and subsequently the price of livestock products coming from intensive systems.

Crop-livestock systems. Crop-livestock systems in developing countries are constrained by farm size and lack of access to inputs and services. These constraints affect soil fertility, crop yields, income generation and ultimately livestock production through the limited provision of high-quality feeds. There is also increasing competition for land and associated opportunity costs.

Pastoral systems. The remoteness and the limited agricultural potential of pastoral systems in marginal areas of the developing world create difficulties for these systems to integrate into the expanding markets for livestock products. This poses a set of different needs related to adaptation of systems to reduce the vulnerability of livestock keepers and their animals and expanding access to markets.

A major driver of change in pastoral systems over the past decades has been the widespread policy to settle pastoralists and allocate them individual land rights. This approach and the increasing encroachment of crop production have seriously affected the viability of these systems by reducing the mobility of livestock and access to feed resources. Although the negative aspects of these policies are increasingly acknowledged, they will continue to shape political processes in many developing countries.

Future implications of structural changes in livestock production systems

In the industrial and mixed crop-livestock systems, rising demand for livestock products will continue to drive structural changes in these livestock production systems and markets. Market transformation, particularly in urban markets, will lead to the increasing importance of supermarkets, large livestock processors and transformation of wholesale livestock markets. Much of this transformation has taken place in the industrialized countries. This pattern is expected to increase in the developing world with a growing share of industrial livestock systems.

Farmers in intensifying crop-livestock systems will diversify their production into dairy and other livestock products even more in response to market opportunities arising from rising demand for high-value foods. Similarly, income growth and urbanization will increase diversification of consumer diets and the share of livestock products in diets.

The major changes in livestock markets are going to take place in domestic markets. The relative importance of domestic markets versus trade in the future will reflect past trends in which domestic market dynamics were far more important than trade. For example, in 1980 and 2001, meat exports and imports were approximately four percent of output and consumption in the developing world. In contrast, the share of domestic urban markets in total livestock consumption has been increasing over the past 25 years.

The growing importance of domestic urban markets as opposed to international trade implies changes of actors in domestic livestock industries, particularly in agribusiness in wholesale markets, livestock processing and the retail industry, with more fresh and processed animal products being sold through supermarkets.

These structural changes in markets, transformation in urban markets, and in retail and distribution sectors in the livestock industry will have profound impacts for the future of smallholders and poor livestock keepers in competing with intensifying industrial and crop-livestock systems in high potential areas. Empirical evidence from Asia shows that smallholder farmers provide up to half of the share of production in dairy and meat markets. Undercapitalized small producers are likely to be squeezed out of dynamic domestic livestock markets. Policy action that supports small producers who can be helped to become competitive will have substantial equity pay-offs. In the absence of such pro-poor policies in the livestock sector, market changes and the entry of new actors in livestock processing, distribution chains and the retail sector can marginalize poor people who depend on livestock for their livelihoods.

High transaction costs and limited access to markets will lead to a dramatic decline of share of livestock production from pastoral systems in marginal areas. Without significant public investments in infrastructure and services, poor producers in these areas will become increasingly marginalized and many will have to leave livestock production as a source of income. Livestock will continue to be important in traditional pastoral systems as sources of food and fulfill multiple other uses, providing traction, transport, skins and hides for shelter.

Implications for livelihoods

In terms of livelihood impacts, the above changes will lead to changes in the role of animal genetic resources for livelihoods in two divergent ways: in intensive systems livelihoods will have a weak link to genetic resources, which will play very specialized production roles. The major livelihood impacts will be through employment. Frequently this will be limited direct employment in large-scale operations but some increased employment will be expected along the value chain. Consumer livelihoods will be affected in terms of impact of prices and of changed attributes of the animal products coming from these intensive systems. Society-wide, there may be negative impacts on livelihoods of traditional smallholders displaced from markets by industrially produced animal products. The net effects will depend significantly on the policy environment and the extent of substitution between animal products produced by industrial systems and smallholder systems.

In crop-livestock systems, livelihoods will be affected by the pressures to intensify and specialize production. Systems may change from grazing to zero-grazed systems, increasing milk production while reducing animal traction. This will imply changes in the labour patterns and possibly gender distribution of work and benefits from animal production. More intensively kept animals will require higher levels of management and external inputs. Increasing livelihood opportunities can be expected to develop in these forward and backward linkages associated with these commodity chains.

Pastoral systems in developing countries tend to have very strong linkages to diverse species and breeds of animals, which allow them to adapt to the exploitation of natural resources with very unique attributes and generally very limited alternative uses. Livelihoods are intimately linked to the animal genetic resources under these conditions. Risk is a major issue and the management of multiple species and multiple outputs is a key way of coping. Increasing competition for the resources, as well as policy orientations towards settling pastoralists, significantly affect these peoples' livelihoods.

In the industrialized world, highly specialized pastoral production systems rely heavily on their animal genetic resources – normally a narrow genetic base comprising one or two commercial breeds of one or two species or a defined crossbred animal population. In relation to pastoral and smallholder systems in developing countries, these systems do not involve much labour. Therefore, the livelihoods of fewer people are generally involved in these production systems.

3.4 Implications of the scope and rate of changes in livestock production systems for animal genetic resources management

The drivers of change and the evolution of the farming systems that they induce will have important effects on livestock biodiversity and its use. This in turn implies that needs and opportunities for human intervention will vary.

In industrial systems, where it is largely possible to adapt the environment to the needs of the animals, highly productive commercial breeds and hybrids are going to be the main genetic pillar. Genetic resources are handled by the specialized private sector firms and traded internationally. Their interest in hardiness or disease-resistance traits will be limited unless diseases emerge for which no alternative control strategies are available or policies require important changes in the management systems, e.g. free-ranging instead of caged laying hens.

In crop-livestock systems, pressure to intensify will be a major force shaping the production system and the genetic resources underpinning it. Significant increases in productivity will be required to meet demand and these will be achieved by simultaneously improving the conditions (feed, health, etc) and adapting the genetic resources. Given the heterogeneous environments, many different breeds will be required. In higher potential areas with good market access this specialization will increasingly involve crossbreeding with exotic breeds. Given the relatively small numbers of animals of each breed required in these niches, these genetic materials will not be produced by private multinational companies but will require active engagement of farmers, public sector and non-governmental organizations (NGOs). These systems will continue to be an important source of genetic diversity and will also demand a range of solutions to fit their specific conditions. As science improves its capacity to understand the role of specific genes and their interaction with environmental factors triggering their expression, the value of local breeds in targeted breeding programmes for these systems will increase. These systems will naturally use a diverse genetic base and will be amenable to engage with *in situ* conservation. Supportive institutional arrangements will be key to driving such efforts.

In pastoral systems in developing countries, high levels of diversity can be encountered and traits of disease-resistance and tolerance of harsh environments are widely present. These systems are frequently declining in livestock numbers and in particular small endemic populations are at risk. In these settings, conservation will require public action because of the limited resources of the generally poor pastoralists. This will be an area where NGOs can be expected to play a key role in assisting in *in situ* conservation.

Given the fragility of institutional arrangements in many developing country contexts and their exposure to natural and human-induced crises, there is merit in designing *ex situ*, *in vitro* conservation strategies as a back up and long-term insurance against loss of diversity in the field. These conservation strategies will need to be coordinated at national and regional/international levels to be efficient and cost-effective.

Climate change considerations add an important dimension to the discussion of livestock biodiversity. Different systems will be affected in different and highly uncertain ways, but access to genetic resources could be a critical ingredient for most adaptation responses in the medium to long term.

Table 5 summarizes major trends in livestock system evolution and their implications for the management of animal genetic resources.

Table 5. Trends in livestock system evolution and their implications for the management of animal genetic resources

Livestock production system: description and trends	**AnGR* – current status in system**	**AnGR management: future strategy for each livestock production system**
Industrial systems (IS)		
Industrial systems changing quickly, expanding globally Controlled system, almost "landless" environment, able to adapt environment to genetics Systems changing to reduce negative environmental impacts, meet market demands and consumer preferences, and address new issues (e.g. animal health and welfare) Changing systems require broader genetic base to address new issues and future shocks	Breeding by private sector, with narrow genetic base in pigs, poultry, cattle High-value genetic stock protected by know-how and traded internationally Limited interest or incentive for private firms in conserving species/breed biodiversity	Commercial systems will continue to *adapt environment to suit genetics* (IS prefer to use most productive breeds and manage other production issues by non-genetic means) IS need to be able to respond to future shocks (e.g. identify tolerance to zoonotic diseases such as avian influenza and also identify more disease-resistant breeds able cope with diseases of intensification without antibiotics) Conserving AnGR of main industrial species (pigs, poultry, cattle) to maintain biodiversity is a long term, public (and private) good to enable IS to deal with future options and new shocks
Crop-livestock systems (CLS)		
Diverse systems with broader genetic base, in industrialized and developing countries; CLS dependent on natural resource (NR) base CLS less in control of environment than IS Future of CLS affected by market demands, NR availability, climate change, land-use options CLS changing and intensifying production, especially in developing countries; but rate of change less than for IS Intensification options – better feed, land, water use, genetic improvement	Developing and conserving AnGR by use in CLS *(in situ)* Genetic base more diverse than IS, as animals need to be in balance with system and coevolve with natural resource base Sustainable delivery of genetic material occurring in some CLS	Need to adapt animal genetics to changing environment CLS need to be able to respond to changing environment, climate change effects, other drivers of change; conserving diverse AnGR in CLS is a public good; Sustainable use of AnGR will help CLS maintain diversity and ability to respond to future drivers of change Smallholders may require incentives to continue to conserve AnGR *in situ* with changing, more productive CLS (e.g. foster niche markets to encourage farmers to keep traditional breeds, for short- and long-term value) Mobility of AnGR critical to maintain future options as CLS change in response to global drivers (mobility favours sustainable use of AnGR) Example of moving adapted AnGR to new areas when climate change affects

		system, such as moving hardier animals to areas more prone to drought. Institutional development to support sustainable AnGR management in CLS (e.g. farmers associations, environmental, food safety and animal health regulations)
Pastoral systems (PS) in marginal areas PS comprise rangelands in industrial and developing countries Systems determined by NR base, usually in marginal environments Multiple value and uses of animals in traditional PS in developing countries PS changing more slowly than IS or CLS as least likely to be influenced by global drivers of change Some PS changing more quickly (e.g in parts of India where there is competition for pastoral land for alternative uses) PS closely related to traditional (cultural) practices and institutions for the management of natural resources and traditional knowledge	PS in industrial countries have narrow genetic base PS in developing countries have diverse AnGR, conserved through sustainable use Traditional AnGR conservation *in situ* by livestock keepers, linked with indigenous knowledge of animals and land	Need to adapt animal genetics to marginal environment Maintaining diverse AnGR is desirable to reduce vulnerability of livestock keepers Future need to improve productivity of PS, maintain livelihoods, with less people likely to be living in marginal lands (e.g. animal health interventions) Genetic solutions through hardier animals, able to adapt to harsher environments, with few interventions Incentives to maintain *in situ* conservation practices and promote sustainable use (e.g. improve market access through better infrastructure; foster niche markets for traditional animal products) Risk mitigation (e.g. better forecasting and strategies for handling risks in PS, such as droughts) Payments for environmental services may mean alternative land-use options that complement or compete with livestock production; requires adaptation of PS and related AnGR, depending on the nature of the environmental service Institutional development to support policies and practices for grazing, water and land-use rights

4. CONCLUSIONS AND NEXT STEPS

What immediate steps are possible to improve animal genetic resources characterization, use and conservation?

Appropriate institutional and policy frameworks are required to improve animal genetic resources management and these issues are being addressed at national and intergovernmental levels, in a process led by FAO to promote greater international collaboration. Based on an analysis of the current situation, the continuing loss of indigenous breeds of farm animals, new developments in science and technology, and the strategies suggested for the future management of animal genetic resources (as summarized in Table 5), there are several complementary actions that can begin to improve the management of animal genetic resources and maintain future options in an uncertain world. The scientific basis that underpins these proposed actions is discussed in more detail in subsequent papers. Four areas for action to improve the sustainable use and *in situ* conservation, characterization and long-term *ex situ* conservation of animal genetic resources are summarized here, and are addressed in further detail in the companion papers:

Sustainable use and *in situ* conservation of animal genetic resources

"Keep it on the hoof" *– Encouraging the continuing sustainable use of traditional breeds and in situ conservation of* animal genetic resources*, by providing market-driven incentives, public policy and other support to enable livestock keepers to maintain genetic diversity in their livestock populations.*

In this context, ***sustainable use*** refers to the continuing use of traditional breeds by livestock keepers, as a result of market-driven incentives. ***In situ* conservation** refers to animal genetic resources conservation measures supported by public policy and, on occasion, public investments to support *in situ* conservation of traditional breeds by livestock keepers.

In regard to encouraging the sustainable use of animal genetic resources, market-driven incentives applicable in developing countries include facilitating access to markets for livestock products coming from traditional breeds. This may include identifying niche markets for traditional products and providing infrastructure (such as transport) to help livestock keepers to get their products to market.

Increasing the productivity of traditional breeds through breeding is also an incentive for livestock keepers to retain these breeds. (The companion paper discusses the role of breeding in more detail.) These breed improvement strategies could also make more use of the widespread crossing that has occurred in traditional populations over time, as livestock keepers seek to improve their breeds.

In regard to encouraging *in situ* conservation of particular breeds, especially in the diversity-rich crop-livestock and pastoral systems in developing countries, the incentives include having public policies that support the conservation of traditional breeds and providing public services (e.g. human and livestock health services, schools, roads) to support communities in livestock producing areas. Such services may encourage people to stay with their animals in rural areas rather than migrate to urban areas where more services are available.

In situ conservation makes use of local and indigenous knowledge, which can also be validated scientifically. For example, some farmers have realized that by crossbreeding part of their herd to an exotic breed, they can make more profit during the good times but avoid the risk of losing all their animals when conditions are bad. Exotic animals tend to be poorly adapted to harsh conditions and tend to die during droughts, for example. Thus genetic variability reduces vulnerability to sudden changes and shocks in the system.

The concept of *in situ* conservation also extends to conserving livestock as part of the landscape, within an overall biodiversity conservation strategy, as a long-term global public good.

"Move it or lose it" *– Enabling access and safe movement of animal genetic resources within and between countries, regions and continents.*

Maintaining mobility of animal breeds, populations and genes within and between countries, regions and continents is one of the key actions for facilitating the sustainable use and thereby the conservation of animal genetic resources. Safe movement of animal genetic resources enables their access, use and conservation for mutual benefit by livestock keepers worldwide. ***Mobility*** here refers to facilitating informed access to genetic diversity, based on systematic breed evaluations and analysing the potential usefulness of various breeds in different environments.

There are benefits and risks in increasing the mobility of animal genetic resources. The benefit is that, in a fast-changing, unpredictable world, mobility of animal genetic resources enables flexibility in response to changing climate, disasters, civil strife, etc. For example, when civil strife has occurred in some part of Africa, animals are moved across borders to avoid their unintended death in conflicts. One risk of increased mobility is that animals moving to different environments may not be adapted to their new environment, livestock system or social system. There are also animal health risks, in terms of the possible spread of disease, or by animals not being tolerant to the diseases prevalent in a new environment. For transboundary movements, these risks as well as the benefit should be identified and shared with stakeholders prior to importation, and risk mitigation steps taken before importing semen, embryos or live animals into a country.

Characterizing animal genetic resources

"Match breeds to environments" *– Understanding the match between livestock breeds, populations and genes and the physical, biological and economic landscape. This* ***"landscape livestock genomics"*** *approach offers the means to predict the genotypes most appropriate to a given environment and, in the longer term, to understand the genetic basis of adaptation of the genotype to the environment.*

In regard to the long-term prospects for this research, the advances in our ability to describe the genome of an animal in unprecedented detail, coupled with our ability (through spatial analysis) to describe the landscape in which it resides – a landscape description that includes biotic, abiotic, human and market influences – are beginning to provide an opportunity to probe genome function in a unique way. This is an approach already used to study the distribution of particular alleles in livestock and to probe the human genome for disease-causing genes. Its potential for understanding the fit between livestock genotype and landscape is significant, and it depends on sophisticated data-management tools. It also offers the opportunity not only to understand the function of the genome, but also to predict the genotype most appropriate to a given environment.

This is a long-term research objective that can be linked with existing data-gathering exercises to add to their value. For example, building in systematic sampling of DNA of livestock breeds in combination with a careful description of the systems under which each population presently functions, and georeferencing the data, will add greatly to our ability to understand and utilize animal genetic resources. For example, we can begin to ask "what combination of genotypes is appropriate for a milking cow under a given management regime, under a given range of disease pressures and under a given set of physical stresses?" Knowing this will enhance the value of genotypes "in the bank" or "on the hoof" and will provide the tools we need to identify intelligently appropriate genotypes for specific agro-ecological niches. (Approaches to characterizing AnGR are discussed further in the companion paper.)

Ex situ conservation of animal genetic resources in gene banks

"Put some in the bank" *– New technologies make* **ex situ, in vitro** *conservation of* animal genetic resources *feasible for critical situations and a way to provide long-term insurance against future shocks in all livestock production systems;*

Improving technology (e.g. cryopreservation) is making long-term, *ex situ, in vitro* conservation of semen and embryos more feasible, affordable and applicable to a wider range of species. The challenge is to decide which animal genetic resources to conserve; how to collect them; where to store them; when and how to characterize them; and who can access, use and benefit from them in the future. It is particularly important to collect the rich diversity of traditional livestock breeds in crop-livestock and pastoral systems in developing countries before it is lost forever.

A risk is that *ex situ, in vitro* gene banks can become "stamp collections", put away in the deep freeze and never characterized. Another potential risk is that this approach may be a disincentive to *in situ* conservation through sustainable use, where the genetic resources are more accessible in the short to medium term and where not only the genetic resources but also the traditional knowledge associated with them are conserved. In fact, *in situ* and *ex situ* conservation approaches are complementary rather than competing approaches, serving short- and long-term needs. *Ex situ, in vitro* animal genetic resources conservation is a long-term insurance policy and an important first step in conserving animal genetic resources for future generations. (Further details on conservation approaches are given in the companion paper.)

Closing remarks

Several important drivers of change are leading to rapid changes in the livestock production sector that have implications for the future management of animal genetic resources. The multiple values, functions and consequences of livestock production systems and their rapid rate of change lead to divergent interests within and between countries. Conversely, the uncertainty about the implications of rapid, multifaceted global change for each livestock production system and the resulting future changes in the required genetic make-up of the animals makes collective action to tackle conservation of animal genetic resources a long-term, global public good. Developing and conserving animal genetic resources will not by themselves solve all these problems, but are important first steps towards maintaining future options.

Advances in science and technology, in areas such as reproductive technology, genomics and spatial analysis, as well as progress in conceptualization of global public good production for the future management of animal genetic resources, should enable the international community to address both the short- and long-term challenges in innovative ways.

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INVENTORY, CHARACTERIZATION AND MONITORING

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Summary

Inventory of species and breeds, their population sizes, geographic distribution and possibly their genetic diversity is generally undertaken as a first step in any national programme for the management of animal genetic resources for food and agriculture. The primary purpose of such an assessment is to document the current state of knowledge in terms of a population's ability to survive, reproduce, produce and provide services to farmers. Starting an inventory requires some knowledge of the inventory items and their characteristic attributes. Inventory and characterization are, therefore, complementary processes, in which the characterization step provides the baseline information as well as the criteria that will be used to establish and update the inventory. Characterization provides data on present and potential future uses of the animal genetic resources under consideration, and establishes their current state as distinct breed populations and their risk status. As use and management of animal genetic resources are dynamic processes, monitoring the status of a population has to be done on a regular basis. Thus, risk status indicators for use during the monitoring process need to be defined following the inventory and characterization steps.

This paper discusses methods and criteria currently available, from research and past experience, for inventory, characterization and monitoring of animal genetic resources, with the view to assist in the development of a more comprehensive framework. Particular consideration is given to emerging tools and technologies. The scope of the review includes all livestock species and their wild ancestors and wild related species. Examples focus on cattle, sheep, goats, pigs and chickens.

1. CONCEPTUAL FRAMEWORK

Genetic diversity within a livestock species is reflected in the range of breeds and populations and in the variation present within each.

1.1 The concept of the breed

The commonly used unit of reference of animal genetic diversity is the breed. Although the term "breed" is generally defined in terms of morphological, geographic, utility and genetic criteria, it is difficult to establish a definition that can be universally applied in both developed and developing countries. Definition of breed identities and characteristics requires at least a preliminary characterization of the breeds that are known to exist within a country. However, using the breed concept may lead to the exclusion of local populations that are not well described or not identified as breeds by the national authorities. In order to avoid missing data relevant to the efficient design of strategies for the management of animal genetic resources, it is useful to recall the different types of populations that are covered by the broad concept of the breed and that should be included in the inventory.

Traditional populations: are mainly local and are considered to be adapted to their environment. They often exhibit a large phenotypic diversity (particularly for coat or plumage colour). They are managed by the farmers with low selection intensity, and are also affected by natural selection. Their genetic structure is mainly influenced by migration events and mutations, which would generally be counter selected in the wild. Population size is generally large.

Standardized breeds: are selected on the basis of morphological traits, with a recognized "standard" breed descriptor, generally established by a community of breeders. They derive from traditional populations, but exhibit less phenotypic diversity as they are selected to meet minimum standards of phenotype. Their genetic structure may be influenced by important founder effects. Total population size may be very variable, depending on history and breeders' organization.

Selected breeds or commercial lines: are characterized by an economic selection objective and the use of quantitative genetics methods. Molecular markers are often used, for instance for parentage testing. These populations derive from standardized breed or from traditional populations. Breeders are organized for pedigree and performance recording. Total population size is generally large.

Derived lines: arise from the use of specific breeding methods. Close inbreeding leads to highly specialized lines which exhibit low genetic variability. Conversely, composite breeds are derived from crosses between standardized breeds or selected lines, and exhibit a high level of genetic variability. Experimental selected lines used for research are part of this group, as they are generally derived from known breeds and selected for very specific traits. Transgenic lines would also belong to this group. Total population size is generally limited, except for composite breeds, which can form the basis of a new selection programme.

These different types of population may be easily identifiable in highly commercialized species such as cattle, pigs or chickens in Europe or Asia, for instance. The classification may not apply directly to other species such as camelids or geese, but can be considered a general framework for all types of domesticated populations.

In addition to these categories, wild ancestors and wild related species are also relevant for inventories. Indeed, spontaneous cross-breeding may still take place between wild relatives and livestock in interface areas. For example, the mountainous regions of north Viet Nam provide permanent contact between wild species and domesticated chicken populations. This "free breeding" increases introgression from wild genomes and plays an important role in maintaining a high genetic diversity and adaptation to particular conditions. Thus, these local populations should undoubtedly be considered in any inventory.

1.2 Descriptors (items) for inventory, characterization and monitoring

Primary indicators of animal genetic diversity should address both between-breed and within-breed components. Using breeds as the main indicator of total animal genetic diversity would miss out the important contribution of within-breed diversity. National authorities need to recognize the limitations of the breed concept and ensure that as much intraspecific genetic diversity as possible is accounted for in strategies for inventory, characterization and monitoring.

Typically, inventory, characterization and monitoring efforts will start by itemizing genetically distinct populations or "breeds", the number of animals per population, and the number of farms that keep these resources. As stated in The State of the World's Animal Genetic Resources for Food and Agriculture (SoW-AnGR), inventory, characterization and monitoring should include the identification, quantitative and qualitative description, and documentation of breed populations and the natural habitats and production systems in which they are embedded. Traits such as adaptation to a harsh environment, disease resistance, provision of environmental services, and product quality may receive specific attention depending on the context. Thus, it is necessary to describe the economic, social and environmental context in which the breeds are used, including cultural aspects of peoples' livelihoods. Furthermore, as socio-economic and environmental contexts evolve, criteria for evaluating breeds and their traits will also have to evolve.

1.3 Relevant scales

In principle, the strategy for inventory, characterization and monitoring should canvass all breeding populations across relevant production systems within a country, and include the sampling of representative animals to generate population descriptor data.

However, depending on the geographical distribution of the breeding population, the population size, breed risk status and economic significance, actions may be undertaken at different scales. For endangered and at-risk populations, they may be carried out at the level of individual animals, or populations of breeding animals in farms or stations. In the case of transboundary breeds, the exercise may involve intercountry collaboration, as in the case of commercial dairy and beef breeds included in multicountry breed evaluation programmes.

2 INVENTORY

A nationally mandated institution for inventory and monitoring is needed. At least in developing countries, this institution should set up a national mechanism to verify whether a particular breed or population represents a distinct unit of animal genetic diversity in the country, and as such needs to be included in the primary inventory.

In any country, it will be necessary to identify the number of farmers or communities that keep a particular population that is registered in the national primary inventory. The national institution in charge of the inventory will collect data from government extension services, as well as from farmers' organizations – at any level from local communities to commercial companies. Involving livestock keepers and breeding organizations in the process has the added value of raising awareness about the value of the breeds in question. Bottom-up approaches also exist, in which a community describes a breed and brings it to the attention of the authorities. Confidentiality issues may affect inventories of commercial lines; breeding companies do not always agree to divulge numbers for the nucleus lines under selection.

In countries or areas where neither extension services nor breeding organizations can be identified to provide census data, on-field counting and systematic georeferencing may be set up as a special effort to improve inventory. Georeferencing will provide very useful information, as it allows geographical and climatic data to be linked to the distribution of breeds within a country.

3. CHARACTERIZATION

The first step of characterization is the primary assessment or baseline survey, which should include collection of data on population size and structure, geographical distribution, production systems in which the breed is found, phenotypic attributes (physical features, performance levels and any unique features), historical development of the breed through exchange, upgrading and selection, and the genetic connectedness of populations when these are found in more than one country (e.g. the N'Dama cattle breed of West Africa). The within-population genetic diversity is measured both at the phenotypic level (phenotypic breed diversity) and at molecular level; the two are complementary. All these data are needed to inform decisions on the utilization, improvement and conservation of the population.

3.1 Production systems and social organizations

As noted in *The State of the World's Animal Genetic Resources for Food and Agriculture*, the term "breed" is often accepted as a cultural rather than a biological or technical term. Hence, in order to depict direct and indirect use values of breeds, they need to be characterized in the context of the production systems and social structures in which they are used. The objective is to allow comprehensive input/output analysis of the genetic resources in the context of the agro-ecosystems of which they form a part. The environmental impact of a breeding population should also be considered as part of the characterization of the production system.
Such data can be collected by survey. FAO has already developed simplified formats for data collection for mammals and poultry. The cost and time needed for such surveys should not be underestimated, but they could benefit from being linked to training programmes, e.g. for MSc and PhD students.

Surveys will be organized differently depending on the institutional background. In developed countries, where commercial and conservation farms keep registers of individual animals and their pedigrees, structured surveys can be used to collect information on production systems and the environment. The procedure should take advantage of current data collection systems and additional costs should be quite limited. Yet, measurements related to environmental impact of breeds and their production systems are generally not included in routine procedures and specific actions are needed to collect such information.

In countries where such data are not regularly recorded, specific surveys need to be set up. For traditional communities in pastoral and farming production systems, participatory surveys and structured interviews can be used to generate data on breeding objectives, breed and trait preferences and production system constraints. In the context of traditional breeds, these descriptions give insights into the multitude of functions and services that breeds provide for their keepers. Statistical sampling procedures can be applied to study localities, farms and individual animals once the sampling framework is defined.

In situations where limited documented information on breed identification and characteristics is available, extensive exploratory surveys may be necessary. However, exploratory surveys have limitations; the facts generated are highly subject to the biases of questionnaire respondents. Thus, steps need to be taken to ground-truth and cross-check findings using complementary procedures such as key-informant interviews, focus-group discussions and reporting-back sessions with respondent communities. Consequently, these surveys become demanding in terms of time, skilled personnel and financial resources. This has been observed, for example, in livestock breed surveys in Zimbabwe and Ethiopia.

Box 1 The Management of Farm Animal Genetic Resources in the SADC Sub-Region project

The implementation of the animal genetic resources characterization project for the Southern African Development Community between 2000 and 2004 demonstrated that the human, financial and networking resources of public institutions and international research and development organizations can be harnessed to run large-scale exploratory surveys. In this particular case, the United Nations Development Programme provided funding, FAO and the International Livestock Research Institute provided expert advice and guidance in the design, execution and evaluation of breed characterization surveys.

3.2 Phenotypic characterization

The different phases of characterization involve morphological attributes, biometrical indices, production levels (growth, reproduction, milk, egg, fibre, traction) and specific adaptations, including survival. Morphological variants may be associated with known genes (coat colour, morphological mutations) and will benefit from their molecular characterization.

It is important that phenotypic measurements (biometrics and performance) should not focus on means or averages alone, but also account for variations. It is the variation that provides the basis for conservation and for present as well as future utilization. For this reason, a large proportion of the population should be included in the assessment of performance.

Performance may be assessed either by direct recording of the animals or by exploiting information that is available in published literature, extension service field reports and reports of breeding units and organizations. Performance testing may be done either on-farm or in testing stations.

On-farm testing
When genetic evaluation is performed utilizing national records from on-farm testing, the associated data can be made available for characterization, and breeding values should be incorporated. However, this is not feasible for pig or chickens breeding schemes run by companies which will not share their data.

For species or countries where there is no national on-farm testing, specific action to collect on-farm data is required. Technicians should be trained to collect morphological data. Pictures should be taken utilizing a tape measure to document phenotypic variability as thoroughly as possible. In traditional communities, indigenous knowledge and practices associated with breed identity and unique utility should also be compiled along with population performance descriptors. A variety of relevant participatory methods exist, including methods that allow livestock keepers to rank breed and trait preferences, including traits with non-market values. Simple criteria such as sales and survival rates provide valuable information.
When georeferencing of phenotypic data is available, further biophysical data from the environment (climate, soil, vegetation cover, water availability, type and level of disease challenges) can be overlaid, and joint analysis in GIS (geographical information system) will help to assess adaptability traits.

On-station testing
On-station characterization makes it possible to evaluate breed performance and potential in a relatively defined and controlled production environment. The limitations are that animals may not necessarily be adapted to the controlled environment and that some traits such as grazing behaviour and response to environmental stressors cannot be measured. Thus, the specific advantages of a local population may not be recognized. Indeed, it is currently difficult to find objective criteria to describe the adaptation of local populations to specific climatic or feed conditions. Research is needed in this field – identifying morphological and physiological predictors for heat tolerance or walking ability, for instance. Moreover, such unknown adaptive traits are usually not captured in a standardized research protocol; new protocols need to be developed. Conversely, a controlled environment allows more precise measurement of individual performance, pedigree recording and estimation of genetic parameters, and provides opportunities to undertake multiple comparisons (breeds and production environments) across stations, so as to assess genotype by environment interactions. A positive aspect of on-station characterization is that it may contribute to the establishment of a nucleus population and contribute to the conservation of the resource being characterized.

Advanced phenotyping
Product quality is generally considered by breeding organizations using precise descriptors, which are defined according to the destination of the product, taking into account indications from nutritionists and food processors. For instance, fat percentage in milk is analysed in terms of fatty-acid composition, and protein percentage can be detailed according to the different types of caseins.

Furthermore, systems have been set up in Europe to associate a product with a certificate of origin, such as Protected Geographic Indication[†] and Protected Designation of Origin[‡], which generally include the breed of origin of the product (Box 2). The same concept is applied for goat meet in Argentina (Box 3). In many African and Asian countries, specific products are also associated with local breeds, and accurate description of the product should be undertaken in order to better define it and, consequently, characterize the breed. This requires capacity-building for the definition of product quality requirements, and the establishment of an official system for certifying that the product and production methods meet these requirements.

Box 2 Differentiation in chicken meat production in France

The French production of chicken meat is differentiated into several categories: standard broiler (SB), label chicken (LB), certified chicken (CF), organic chicken, and *Appellation d'Origine Contrôlée* (AOC = Protected Designation of Origin) for the Bresse breed only. Whereas LB production represented nearly 100 million chickens in 2002 (*www.synalaf.fr*), the Bresse AOC represented 1.4 million chickens raised only in the Bresse geographical area as defined by law. The LB category was created in 1965, to promote product quality throughout the production process. The LB and CF legal definitions do not require reference to a particular breed, but only slow-growing lines are eligible. These slow-growing lines are generally characterized by a colored phenotype, easy to distinguish from the white plumage of SB. The philosophy of AOC is quite different since it defines a geographical district which is characterized by specific features of the natural conditions and production system. For the Bresse, the district was defined as early as 1936 and the protection of the name "*Volaille de Bresse*" was enshrined in law number 57-866 on August 1, 1957. The Bresse breed standard includes white plumage and blue shanks, which is a rare association among French poultry breeds. A fixed set of growing conditions (density, open-air access, type of feed) must be applied for at least 9 weeks, starting from 5 weeks of age. Then, the finishing period, slaughtering conditions and carcass processing are strictly regulated. The minimal age at slaughter for the Bresse is 112 days, whereas it is 84 days for LB and 39 days for SB. Tasting panels are regularly organised to check the meat quality. The selection procedure for the Bresse breed has also been strictly regulated and is managed by a selection center (CSB) which is working in close collaboration with farmers. The Bresse breed is the only local French chicken breed the population size of which has not decreased since 50 years, and credit must be given to the AOC for this success (Verrier et al., 2005).

Box 3 Differentiation of goat meat in Argentina

The traditional goat production system from North Neuquen (Patagonia, Argentina), developed by transhumant goat keepers is a marginal system with low economic input and fragile environment but with a high cultural capital, an adapted genetic resource and a product with high reputation but not differentiated. To overcome this situation the application of a Geographical Indication was developed. This process was based on the organization of the local goat meat marketing chain and the description of technological properties of the product of the Neuquen Criollo breed. The chain actors developed a common vision about the system and its identity, which is reflected in the Protocol of the Designation of Origin of the "*Criollo Kid of North Neuquen*". A study on the product's typicial characeristics and quality has contributed to define quality indicators and traceability of the product. As a result, the goat keepers organizations have been empowered, a common ground of communication has been established enhancing the understanding level among local actors, which was previously not existent. This has reinforced regional development and given projection to sustainability of the system and genetic resource (Pérez Centeno et al., 2007)

Disease resistance is a high priority for several reasons: local breeds survive in harsh environments and this needs to be better understood; epidemics are a major threats for all animal genetic resources across the world; climatic change is likely to increase the spread of tropical

[†] Protected geographical indication: the name of a region, specific place or country describing a product originating in that region, specific place or country and possessing a quality or reputation which may be attributed to the geographical environment with its inherent natural and/or human components.

[‡]Protected designation of origin: the name of a region, specific place or country referring to a product originating in that region, specific place or country and whose quality or other characteristics are essentially or exclusively due to a particular geographical environment.

diseases to temperate areas. In addition to claims that local breeds are adapted and resistant, scientific evidence has been obtained in several instances (examples are reported in *The State of the World* report). The effect is particularly well documented for parasitic diseases, which are very prevalent in tropical areas, with local breeds maintaining a better performance in the presence of parasites and/or exhibiting lower levels of parasite infestation. Generally, this condition is better described as tolerance, a typical example being trypanotolerance in cattle. Generally, more data are needed on exposure and response of animal populations to parasites, viruses and bacteria. One delicate question involves possible confusion between resistance and a healthy-carrier state for a given pathogen. True resistance, in which the host does not allow the pathogen to disseminate, is the objective of most research studies in developed countries. This is consistent with the assumption that it will be possible to eradicate the pathogen. However, this seems unrealistic for tropical parasites. Thus, research is focusing on defence mechanisms, in order to better understand the permanent race between hosts and pathogens. Furthermore, epidemiological studies suggest that pathogens may adapt more easily to uniform genotypes, and that genetic variation of the host is one key to limiting pathogen expansion. Thus, cooperation between Northern and Southern countries is needed to better characterize the potential usefulness of animal genetic resources for disease control. This may benefit from progress in genomics and the identification of genes for resistance to major diseases, as well as in the understanding of general immune response.

3.3 Molecular characterization

The impressive development of molecular tools in the past 20 years benefits the characterization of animal genetic resources in many ways – which are already well documented in *The State of the World* report. It is important that countries are aware of what questions molecular tools can or cannot answer at present, and how this may change in the future. It is also important to consider that the broad array of tools that is available in the case of the “big five” species is not available for species with a more limited geographic distribution, but which should not be neglected.

Some practical considerations
The first step is to collect samples of sufficient quality from representative animals of the population to be described – either a well-known breed or a non-described population (FAO, 1993). The general recommendation is to sample 30 to 50 unrelated individuals, in flocks or herds covering a wide geographical area, taking into consideration historical exchange of breeding stocks, and agro-ecological zones as possible barriers to gene flow between populations. These are minimum numbers. Ideally, half the sample should be females and half males. A clear description of the sampling procedure is needed, both for immediate use of the samples and to allow the samples to be used for future studies. Ideally, the animals sampled should also have been subject to phenotypic characterization.

The required DNA quality depends on the intended future use. Several protocols are available, and good quality should be the aim. Blood or ear-tissue samples are ideal for typing nuclear and mitochondrial DNA (mtDNA) markers, but such sampling is not always accepted by the farmer. It is possible to extract sufficient DNA from hair bulbs to allow the typing of microsatellite DNA markers, but such samples are not easy to work with in the case of mtDNA and other markers. Extraction kits are expensive, but should provide repeatable quality. Manual extraction needs trained personnel. Whatever the protocol, DNA quality should be checked before samples are used or sent for genotyping.

Molecular markers involve genomic and mtDNA loci. Microsatellite markers are most commonly used because they are multi-allelic and numerous, and can be genotyped on automatic machines. New microsatellite marker sets of 20 to 30 loci per species recommended by the ISAG§/FAO Standing Committee are available for most species (FAO/ISAG, 2004). It is highly recommended that a core set of a minimum of 15 markers be included so as to allow comparative studies across

§ International Society of Animal Genetics countries. Merging genotype data sets produced in different laboratories has proven to be possible though quite challenging. Exchange of reference samples between laboratories is mandatory, and training of technicians to score the genotypes following the same procedure is necessary. Statistical methods for meta-analysis are also under development to make the best possible use of available data in order to merge all information and facilitate international comparisons. The problem of standardizing microsatellite typing is not encountered in the case of typing single nucleotide polymorphisms (SNPs) because technologies are available to provide standardized reading of SNPs and to produce data that can be merged between laboratories. SNPs are discussed in more details in Box 7.

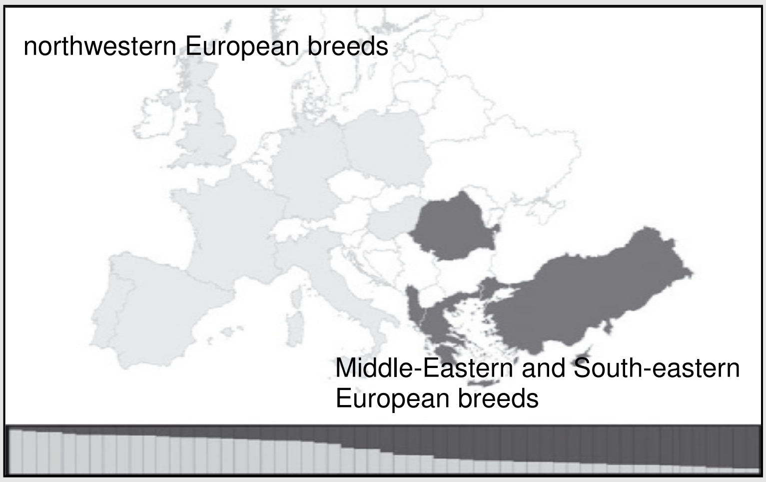
Assessment of genetic diversity with anonymous DNA markers

The first question that anonymous DNA markers can answer relates to the diversity level within a population, which can be described by number of alleles, number of private alleles, or observed and expected heterozygosity. Generally, the diversity level of domestic breeds/populations has been found to be lower than that of wild relatives and ancestors. Diversity can be expected to have gradually declined during the dispersal of livestock populations from their centres for domestication or origin to their current locations, mainly as a result of random genetic drift. However, this pattern may be distorted by the introduction of exotic breeds, cross-breeding between populations, admixture of populations from different centres of domestication and human selection. Thus a careful examination of the population's history is warranted. It is also well known that heterozygosity estimates are not so sensitive to the change of number of alleles, particularly in the case of multi-allelic microsatellite markers. Therefore, the adjusted mean number of alleles according to sample sizes could be a better parameter to measure genetic diversity within breeds or populations.

Methods have been proposed, and are still under development, to estimate the effective population size of a breed or population from molecular data, particularly from linked markers. It is also possible to detect departure from the equilibrium state either due to excessive inbreeding or to population fragmentation in subgroups that have few or no exchanges between them. Thus, DNA markers can be used for monitoring conservation programmes aimed at avoiding inbreeding, genetic bottlenecks and fragmentation. Furthermore, they can be used to identify "livestock biodiversity hotspots" as priority areas for conservation of indigenous livestock populations. Typically, populations containing large variation at anonymous loci are expected also to exhibit large variation for functional traits. Thus, DNA markers could be most useful in cases where little information on population history is available. However, anonymous markers do not at present provide a reliable prediction of phenotype; they do not replace performance measurements and should not be used alone to make conservation decisions.

Box 4 Sheep biodiversity

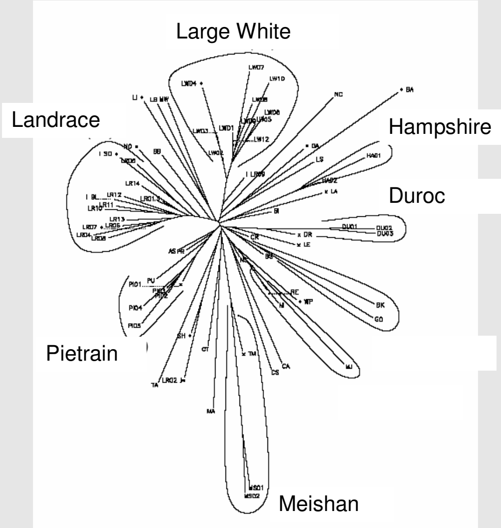
The ECONOGENE project combined a molecular analysis of biodiversity, socio-economics and geostatistics to address the diversity and conservation of small ruminants in marginal agroecosystems.



Adapted from Peter et al., 2007

The population structure and genetic diversity of 57 European and Middle Eastern sheep breeds from 15 countries were analysed by typing 31 microsatellite markers, thereby extending the available knowledge of sheep diversity at the molecular level. The domestication centre for sheep lies in the Near and Middle East, and the results showed high levels of genetic variation among Middle-Eastern and South-eastern European breeds. The analysis of markers and of the spatial distribution revealed the occurrence of two clusters, one with northwestern European breeds and the other with Middle-Eastern/south-eastern European breeds, as depicted in the figure.

The second area in which DNA markers provide useful answers includes questions of relatedness between populations, detection of admixture, introgressions and breed identity. Between-breed variation may be described by genetic differentiation indices, such as F_{ST} for which statistical significance can be calculated in order to conclude whether or not genetic differentiation takes place between pairs of populations. Allelic frequencies for molecular loci also provide the basis on which to calculate genetic distances. As mentioned in *The State of the World* report, phylogenetic reconstruction of the evolution of breeds or populations is not well adapted to the dynamics of domesticated populations, which do not diverge strictly from a common ancestor and may include cross-breeding, admixture and introgression events in their histories (Box 4). In the case of selected lines derived from the same breed, phylogenetic reconstruction with neighbour-joining tree can reveal clustering (Box 5).

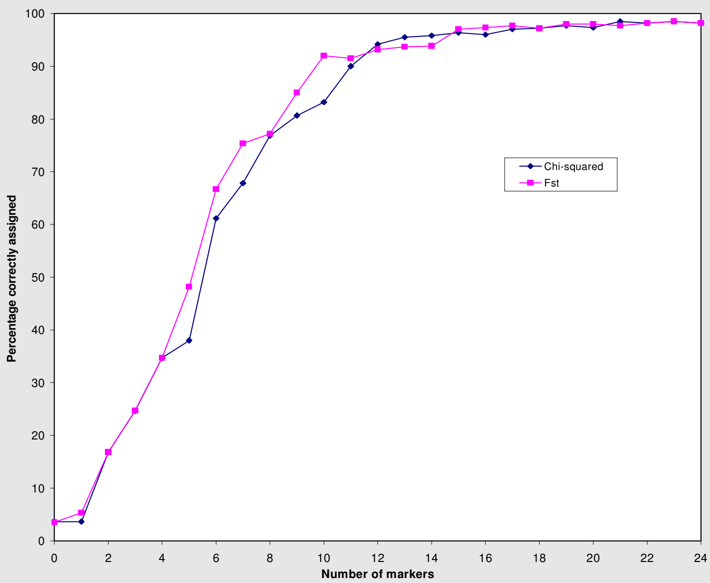


Box 5 Pig biodiversity

The European PigBiodiv project used 50 microsatellite markers to assess the between- and the within-breed genetic diversity for a set of 59 pig breeds. The resulting structure of 8 groups (bootstrap) showed within-breed clustering of pig lines. The national populations of major breeds and the commercial lines were clustered around their breeds of reference (Duroc, Hampshire, Landrace, Large White and Pietrain) in most cases. The Meishan breed represented a specific outgroup. Local breeds did not group into one cluster and appeared to be scattered within the global frame. Using only 18 markers decreased the reliability of the clustering, particularly for the Landrace breed (Adapted from San Cristobal et al., 2006).

Multivariate methods offer a different approach, which unlike phylogenetic trees, does not rely on any evaluative assumption. Bayesian clustering has been shown to be very efficient for the assignment of individuals to breeds or populations and as a means to detect population structure and admixture without any prior information on population ancestry. Recent results obtained in chicken populations, both traditional and commercial lines, showed that more than 90 percent of individuals could be assigned to their true breed of origin according to their genotypes for microsatellite markers (Box 6).

Box 6 Breed assignment with anonymous markers



The AvianDiv project used 27 microsatellite markers to genotype 30 animals from 20 chicken populations, ranging from the wild ancestor to highly selected commercial lines. After an analysis with the 'Structure' software, it was possible to assign birds to their correct breeds with 90% efficiency using 12 markers. After 24 markers, efficiency remained close to 97%. Correct assignment of commercial birds to their true line of origin was the most difficult and required all markers.
(Adapted from Rosenberg et al., 2001)

Thus, DNA markers allow the definition of the genetic entity behind the breed. This can clarify the procedure of inventories and identify the base population for conservation programmes. Knowledge of the molecular identity of certain breeds or populations may also be used to establish biological identification systems for certification and traceability of living animals and derived products.

In addition to nuclear markers, both mtDNA and markers from the Y chromosome of mammals provide additional information on the history of domestication and introgression events. Very interesting results have been obtained for ruminants in this respect. These data may also be useful because they shed light on peculiar adaptive traits that these populations may have accumulated over time.

Known genes and functional diversity

Progress in genome annotation and quantitative trait loci (QTL) programmes has led to the identification of many candidate genes that are likely to influence traits of interest. QTL programmes and genome databases are available for the "big five" species. Comparative genomics may also facilitate the assessment of functional diversity by transferring knowledge between species. Significant progress has been made in the molecular identification of genetic abnormalities as well as major genes affecting meat quality or muscular growth. Some causal mutations, as well as diagnostic methods for these mutations, have been patented, and new alleles may be present in some indigenous populations. Therefore, the issue of intellectual property (IP) arising from the discovery of functional diversity and exclusive or non-exclusive use of this IP has to be addressed. As far as QTL are concerned, finding genes responsible for the quantitative effect on the performance is still rare. Furthermore, the effect of a QTL region may depend on the genomic background: epistatic interactions are known to take place, so that a given QTL region identified in one population may not be relevant for another population. An integrated strategy using molecular markers would be to map the genetic diversity among indigenous livestock breeds/populations to test hypotheses about which of them may carry unique QTL for disease resistance.

The transcriptomics approach has enabled the exploration of gene expression patterns for thousands of genes simultaneously. But this approach has not been used to a large extent for diversity studies. It raises a number of questions, regarding the tissue to be sampled, the stage of sampling, and very often requires animals to be slaughtered. The best examples deal with the study of disease resistance, where multigenic expression patterns can efficiently describe the mechanisms involved in defence responses, and can identify relevant differences between breeds. Thus, more experimental data are needed before gene expression patterns are incorporated into characterization.

The final effector molecules are proteins. Proteomics has also made significant progress, although it raises delicate methodological issues and has not yet been applied to the characterization of genetic diversity. Research is needed to improve this approach which may open the way to intensive phenotyping.

Prospects with high-density single nucleotide polymorphisms

The full genome sequence is or will soon be available for chickens, cattle, pigs and sheep (and goats) and large numbers of *single nucleotide polymorphisms* (SNPs) are becoming available (Box 7). As compared to microsatellites, mtDNA and polymorphisms of known genes, the use of high-density SNP markers offers quite new perspectives: these markers are so numerous that they may unravel the fine structure of the genome and identify chromosomal segments showing selection signatures. This will greatly improve our knowledge of population genetic make-up. Large-scale SNP typing has already started in selection programmes for cattle (dairy and beef) and chickens. Performance recording is still necessary at crucial steps of characterization programmes, to define the association between genotypes and desired phenotypes. Alleles, haplotypes or quantitative trait nucleotides (QTN) could then be used to estimate a breeding value genome-wide. This represents one step forward from the current marker-assisted selection programmes, that track a limited number of QTL regions to whole genome selection. Thus, the whole organization of data collection may change in the coming years. FAO's information system will have to be updated to take into account these trends.

Box 7 A new approach of genome diversity with SNPs
Large numbers of SNPs have been or will be generated as companion programmes of the genome sequencing efforts undertaken for the "big five" species. SNPs are mainly bi-allelic due to the low frequency of mutations. Therefore, only a higher number of SNPs can achieve information content comparable to that obtained using a given number of microsatellite markers. Characterization of the same set of ten chicken breeds using 29 microsatellite markers and 145 SNPs confirmed that increasing the number of SNPs had a higher impact on the reliability of the results than increasing the sample size (Hillel *et al*., 2007). Heterozygosity and allelic-richness estimates obtained for SNP markers exhibit a lower order of magnitude as compared to microsatellite markers, with values in the range of 0.34 and 1.94, respectively, across a set of Holstein-Friesian bulls (Zenger *et al*., 2007). It is likely that systematic molecular studies of animal genomes will use SNPs and handle questions of selection and management of genetic diversity at the same time. Cost of typing SNPs is steadily decreasing, but SNPs are valuable only when they are very numerous (e.g. more than 3 000). Therefore, the absolute cost of typing is still a matter to be considered.

4. ADVANCED INVENTORY AND MONITORING

All countries need an active inventory and monitoring strategy for their animal genetic resources – to better understand, use, develop, maintain, conserve and access these resources. The *Global Plan of Action for Animal Genetic Resources* recognizes the need to have a country-based strategy so that activities for inventory and monitoring can be linked and coordinated with relevant country-level action plans such as agricultural censuses or livestock population surveys. Indicators are needed for population trends, breed risk status and changes in the production environment. Apart from the opportunity of carrying out meta-analysis of nationwide data to establish trends and information gaps, country-based strategies also encourage the establishment of information databases of animal genetic resource inventory which can provide a comprehensive source of information for research, development of breeding strategies, conservation programmes, policy frameworks and even training.

4.1 Monitoring driving forces and describing production environments

Production environments are dynamic, albeit at different scales and rates. As discussed in the introductory paper to this series, the major drivers of change that are of relevance to the management of animal genetic resource diversity are population growth, urbanization, and the associated changes in the structure and volume of demand for livestock products, globalization, climate change and global health hazards such as avian influenza. All of these drivers should be monitored to predict future scenarios and allow improved preparedness to meet future challenges.

Indicators related to production environment were elaborated at an FAO expert consultation which met in Armidale, Australia in 1998. Five main criteria (climate; terrain; disease, disease complexes and parasites; resource availability; and management) were identified as the basis for the characterization of production environments for all livestock species, with three to seven indicators for each criterion (FAO, 1998). The framework is demanding in terms of resource requirements and needs to be operationalized, but can be used to select priority criteria and indicators that better meet specific needs.

The application of georeferencing tools can make a major contribution to improving the scope and scale of advanced inventory and monitoring both at country and global levels.

4.2. Monitoring animal populations

Through their ratification of the Convention on Biological Diversity, countries are committed to inventory and monitoring of the status of their animal genetic resources. However, country reports prepared during the *State of the World* reporting process show that national inventories have either not been carried out or are still incomplete.

Monitoring requires regular checking of population status, and the evaluation of trends in the size and structure of breed/populations, their geographical distribution, risk status and genetic diversity. If breeders' associations or other groups interested in breed maintenance and promotion exist, it may be possible to update the inventory annually. In the absence of such groups, the mandated national institutions must ensure that periodic assessment of breed status are carried out ideally on annual or biennial basis, or at least at intervals of one generation for the species in question. This would require comprehensive updating at intervals of about eight years for horses and donkeys, five years for cattle, buffaloes, sheep and goats, three years for pigs and two years for chickens. Once a breed has been identified as at risk, a more intensive monitoring programme is needed on an ongoing basis.

As noted in *The State of the World* report, monitoring can be an extremely expensive aspect of the management and should take as much advantage as possible of existing resources and activities.

4.3 Defining indicators for animal genetic diversity

A compromise has to be found between the ideal list of indicators needed to provide accurate information, and the cost of collection and ease of interpretation. As stated by OECD (2001), four main criteria may be used to assess the value of indicators: policy relevance, analytical soundness, measurability and interpretation. In general, a small number of indicators is preferable in terms of measurability and communication, but relevant information needs to be captured in order to support sound decisions.

The existing FAO definitions of breed risk status (extinct, critical, endangered and not at risk) are based on numbers of breeding females and males, but do not relate to how matings are handled (e.g. random or high selection intensity within breeds, use of crossbreeding). Major drivers of change can lead to rapid changes in the population size and structures of locally adapted breeds. Regular monitoring is therefore required, at least for those breeds classified as critical or endangered. At present, most national livestock censuses do not contain breed-level data, therefore, regular reporting of breed population numbers does not usually take place. In addition to population size, the number of farms and number of breeding organizations could be considered. The number of breeding males should be made available. Such a monitoring scheme can serve as the basis for national early warning, so that timely management interventions can be planned. Monitoring programmes need to ensure that feedback is provided to farmers, researchers and other stakeholders.

Recent research suggests that several issues need to be taken into account for the development of indicators for animal genetic diversity:

- the concept of the breed as a genetic entity for measuring diversity would benefit from the use of molecular markers for the assignment of individuals to breeds ;
- the assessment of breed risk status should not rely on population size alone, but would benefit from more accurate parameters calculated on the basis of extensive pedigree analysis, such as inbreeding coefficients of current breeding animals, or the number of ancestors with a cumulated contribution of 50 percent of the total gene pool;
- in the absence of pedigree recording, loss in diversity may be monitored using molecular markers, particularly on the basis of the adjusted mean number of alleles calculated for reference sets of microsatellite markers;
- occurrence of introgressions or fragmentations may be monitored with molecular markers, combining nuclear markers and mtDNA, provided that reference data sets for a range of populations are available for comparative analysis within a country or region.

Target values for country-based early warning tools are yet to be developed. It is essential to establish both baseline (inventory) and follow-up (monitoring) assessments to effectively inform decision-making in the management and utilization of animal genetic diversity. Monitoring of diversity should address both the level of between-breeds diversity, with setting up conservation programmes for endangered populations, and the level of within-breed diversity with updating rules for the genetic management of the population (Fikse & Philippson, 2007).

5. CONCLUSIONS AND RECOMMENDATIONS

Inventory and characterization of animal genetic resources should be an iterative process. Regular updates are necessary, because animal genetic resources are exposed to strong driving forces, both from the viewpoint of production systems and emerging technologies.

Data from all types of populations are relevant for the Domestic Animal Diversity Information System (DAD-IS) managed by FAO. In order to minimize information gaps, the concept of the breed should be understood in a broad sense. Inventory should include criteria to assess within-breed diversity. National databases have to be set up and should be coordinated at a regional level and with FAO, in order to facilitate the comparisons and the updating of information.

A comprehensive description of production environments is needed in order to better understand the comparative adaptive fitness of specific animal genetic resources. It will also help to identify threats and options for the management of these resources.

On-field and on-station phenotypic characterization are complementary. Performance data should focus on variability as much as possible and not only include means. Defence mechanisms against pathogens should be a priority, given the significance of the threats posed by epidemics and climate change.

It is likely that microsatellite markers will remain the first choice for the analysis of genetic diversity in many domestic species in the near future. Steps should be taken to support comprehensive multicountry studies, and to facilitate meta-analysis. On the technical side, this requires improved exchange of reference samples and standardization of genotyping procedures. From the methodological perspective, appropriate models need to be developed and tested.

Anonymous markers provide a range of information, from population history to breed identity. However, the number of markers which is sufficient for population genetics studies does not allow any prediction of performance. Thus, available molecular genetic markers should be used together with phenotypic data.

Recent technologies for large-scale gene expression studies and high-throughput SNP genotyping are likely to greatly modify characterization tools, with the prospect of better connecting phenotypes to genotypes. Costs are still too high for these procedures to be used in systematic surveys of genetic diversity, but in species such as cattle and chickens in which the genome has been sequenced, these technologies are likely to rapidly prove their usefulness in achieving a comprehensive approach to the assessment of genetic diversity.

Data on production systems, phenotypes and molecular markers should be used altogether in an integrated approach to characterization. Decisions regarding conservation should incorporate all descriptors. Conserving without documenting would be useless. National authorities should be aware that sharing information and data is essential to support cost-effective decisions in the management of animal genetic resources.

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SUSTAINABLE USE AND GENETIC IMPROVEMENT

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Summary

Sustainable use of animal genetic resources for agriculture and food production is proposed as the best strategy for maintaining their diversity. Achievement of sustainable use would continue to support livelihoods and minimize the long-term risk for survival of animal populations. The concept of sustainable use has economic, environmental and socio-cultural dimensions. Sustainable use of animal genetic resources also contributes to food security, rural development, increasing employment opportunities and improving standards of living of keepers of breeds. Supporting the rearing of breeds through better infrastructure, services, animal health care, marketing opportunities and other interventions would make a significant contribution to the sustainable use of animal genetic resources.

Sustainable use envisages the use and improvement of breeds that possess high levels of adaptive fitness to the prevailing environment. It also encompasses the deployment of sound genetic principles for sustainable development of the breeds and the sustainable intensification of the production systems themselves. Sustainable use and genetic improvement rely on access to a wide pool of genetic resources.

Genetic improvement programmes need to be considered in terms of national agriculture and livestock development objectives, suitability to local conditions and livelihood security as well as environmental sustainability. Genetic improvement can involve choice of appropriate breeds, choice of a suitable pure breeding or crossbreeding system and application of within-breed genetic improvement. The choice of appropriate breeds and crossbreeding systems in developed countries has been a major contributor to the large increases in productivity, and has benefited greatly from the fact that developed country animal genetic resources are well characterized and relatively freely exchanged. Where proper steps have been followed by careful assessment of demand, execution, delivery, impact and cost–benefit analyses, successful within-breed improvement has been realized within indigenous populations in developing countries. Breeding objectives and programmes for subsistence oriented and pastoralist systems are likely to be entirely different from conventional programmes. Crossbreeding has been most successful where it is followed by a rigorous selection programme involving livestock owners' participation and substantial public sector investment in the form of technical support. In any genetic improvement programme, inbreeding needs to be monitored and controlled.

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Within-breed genetic improvement is normal practice in the developed world, and has become a highly technical enterprise, involving a range of reproduction, recording, computing and genomic technologies. Emerging genomic technologies promise the ability to identify better, use and improve developing world animal genetic resources in the foreseeable future. Useful systems can, however, be established without the need for application of advanced technology or processes.

1. INTRODUCTION

Sustainable use is the use of components of biological diversity in a way that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations. This is the definition of "sustainable use" proposed by the Convention on Biodiversity (CBD). *The State of the World's Animal Genetic Resources for Food and Agriculture* (FAO, 2007) identified key elements of this concept as it applies to animal genetic resources. It reviewed existing concepts but did not attempt a comprehensive description of the state of the art. The general conclusions of the SOW-AnGR were that there is a need for the concept of "sustainable use" to be "interpreted in the context of agricultural biodiversity, and for concrete management strategies to be developed for AnGR". After the drafting of *The State of the World* report, FAO held an expert meeting that identified the guiding principles of sustainable use, made specific recommendations addressing relevant aspects of the concept and focused on work required to clarify and develop the concept further. This paper describes the state of the art of scientific thinking on the key technical issues, options and opportunities in relation to sustainable use of AnGR.

Animals are reared in production systems, each with its unique geographical, environmental, cultural and socio-economic context. Sustainable use of animals for agriculture and food production in robust, ecologically compatible production systems is widely accepted to be the best strategy to maintain their diversity. Continued use of animal genetic resources within the environment in which they were developed provides a number of advantages, including maintenance of local knowledge about how best to manage the animal, maintenance of the production environment, and continued opportunities for the livestock to adapt to local production conditions and the needs of the society (FAO, 2006a). However, allowing movement of animal genetic resources to new locations and production and market systems is also a way of promoting their sustainability. Use of animal genetic resources inevitably includes development. Animal genetic resources are dynamic resources, changing with each generation in interaction with the physical environment and according to the selection criteria of their keepers (Wurzinger *et al*., 2006). The concept of sustainable use therefore encompasses genetic improvement.

Even in the most rapidly developing countries, there are striking inequities in access to the benefits of economic development. Many families continue to keep a few animals of traditional breeds, often with very low use of external inputs, to provide a wide variety of products and services for household consumption and for sale in local markets. The development of opportunities for most of these families to intensify production and participate in national or niche markets or to find more lucrative non-agricultural employment is not likely to occur in the near future. In the meantime, continued access to well-adapted, local animal genetic resources will remain important for them (FAO, 2006b). Support for sustainable use of animals in developing countries will thus contribute to the broader socio-economic goals of livelihood security and rural development, increasing employment opportunities and standards of living in rural areas and reducing migration to cities. Animal genetic resources play an important role in maintaining vital rural areas in developed countries also. In addition, in both developing and developed countries, animal genetic resources supply nutritious, protein-rich foods to people.

This paper discusses opportunities to enhance sustainable use of animal genetic resources, given the identified drivers of change articulated in paper 1, mainly in agropastoral systems in marginal areas and crop–livestock systems in high potential areas. This focus is justified because industrial production systems using commercial breeds are already well developed, supported by heavy investment of capital, other resources and knowledge, and have efficient monitoring and corrective mechanisms in place if needed. The paper also presents the current scientific understanding in the area of genetic improvement and sustainable breeding programmes for development of animal genetic resources. The impact of revolutionary technologies in the field of genetic improvement and issues related to intellectual property rights are also discussed.

2. FACILITATING SUSTAINABLE USE WITHIN PRODUCTION SYSTEMS

Animal genetic resources form the basis of the livelihood and the cultural identity of a large number of farming and pastoral groups. Livestock have a critical role in maintaining sustainable agricultural systems, assuring food security and alleviating poverty. This role is especially important given the prospect of climate change or emerging diseases and the unpredicted rate and consequences of such change. It is expected that sustainable use would lead to the maintenance of vibrant and vigorous populations of breeds in their appropriate production systems. Increasing the profitability of rearing animals, particularly by increasing their market value, as well as enhancing their non-market values can maximize the probability of their continued use in the long term. Adaptive fitness and increased productivity can be achieved and maintained more effectively by improving inputs, environmental conditions and genetic resources concurrently. There is a range of alternatives and opportunities available for such facilitation including institutional strengthening. There are, however, also many examples where opportunities have been wasted or inadequately exploited due to inappropriate policies and lack of support in critical areas (Philipsson, Rege and Okeyo, 2006).

2.1 Targeting breeds that require interventions

In general, more effort to promote sustainable use needs to be directed to those breeds that are likely to become threatened without support. Another factor to be considered in the targeting of interventions is the specific characteristics of breeds that make them unique – for example, adaptive traits such as disease and heat-resistance or specific feeding behaviour. Other criteria might include a focus on breeds that are specific to restricted regions or are unique in terms of their genetic, morphological, functional or cultural characteristics or the products that they produce. Development of a breed is likely to be more successful where there is a local community that highly values the breed in question and has a long history of local knowledge and experience of working with the animals. Continuous monitoring of the status of breeds by periodic breed surveys and censuses would help to provide information on population trends and impending threats. Such data can inform decision-making and help in formulating sound development schemes. This aspect is dealt with more comprehensively in the companion paper on characterization.

2.2 Strengthening production systems

Breeds fit into specific production systems and agricultural landscapes. If particular production systems disappear, the associated animal populations may no longer continue to be used sustainably. Strengthening these production systems so that they are robust in the face of changing circumstances would support the sustainable use of animal genetic resources. Various ways of strengthening these systems are elaborated below.

- ***Opportunities for small changes in farming systems.*** Small changes in farming systems, designed according to the prevailing climate, resource profile and agricultural practices, can make livestock rearing more profitable and beneficial to the farming system and thus more sustainable. One example is to use novel ways of integrating crop farming and livestock rearing such as ley farming. Another example of an alternative model of farming using livestock is growing grass/leguminous forage on marginal, rainfed lands and rearing livestock instead of sowing grain crops that usually do not yield any grain because of inadequate rainfall.

- ***Provision of technical services***: In some cases, technical improvements to animal nutrition, management and health may improve the economic viability of animal populations. The sustainability of animal genetic resources in existing production systems could be improved substantially by provision of basic veterinary services, including disease prevention measures such as vaccination. Improvements in management and genetics go together in reality as changes in one create new opportunities for the other. Provision of credit to purchase animals and for capital expenditure and a reliable supply of feed resources can provide significant impetus to the rearing of endangered breeds. These services may have to be tailored to specific needs – for example, they need to be mobile for nomadic herding. Other improvements to rural and agricultural infrastructure would also encourage livestock rearing in addition to other general benefits, for example by improving market access through provision of market information and objective pricing structures.

- ***Ensuring continued resource availability to livestock keepers***: Sustainable use of animal genetic resources is closely linked to the continued availability of adequate grazing and water. Pastoralist production systems are increasingly under threat worldwide. The reasons for this are numerous:
  - deterioration of natural pastures as a result of droughts, inappropriate management of grazing and soil erosion;
  - curtailed access of livestock to common property resources;
  - diversion of grazing lands to other uses such as irrigated crop-farming, establishment of industries, urbanization or creation of national parks;
  - increasing difficulties in migration owing to increased cross-border disease-related controls, and traffic and highway codes that restrict livestock movement along and across major highways.

There are also other increasing demands, such as for biofuel production, on common property resources and government lands in almost all countries. A pragmatic approach would be to take into account the vital role of animal genetic resources in diverse spheres, from production of much-demanded animal protein to maintenance of fertility of farmlands and creation of space for animal genetic resources in land-use plans (Köhler-Rollefson and LIFE Network, 2007).

- ***Capacity building.*** Training will help to inform livestock keepers of the latest scientific developments applicable to their livestock, such as availability of new vaccines, and will help to protect them from inappropriate advice (Malmfors *et al*., 2002). Training should build upon existing local knowledge of the production system and enable livestock keepers to make informed decisions.

- ***Improving the status of animal genetic resources by raising awareness among policy- and decision-makers.*** Sustainable use of animal genetic resources has not achieved a high priority in the strategies of many governments or national and international funding agencies. In the Consultative Group on International Agricultural Research (CGIAR), institutional capacity and availability of funds are generally skewed heavily towards the plant sector (FAO, 2006b). Animal husbandry usually gets a raw deal compared to crop farming in governmental financial allocations because of inadequate awareness of policy-makers of the importance of livestock. It is therefore necessary to raise the awareness of the contribution of livestock to national economies and to the well-being of large numbers of families to give a higher profile and status to livestock rearing. Raising awareness will help in encouraging policy-makers to develop sound policies that are beneficial for sustainable use of animal genetic resources rather than policies that may have an adverse impact on livestock rearing. For example, supportive public policy and long-term technical support systems are largely responsible for the success of the dairy subsector in India (Kumar, Birthal and Joshi, 2003).

- ***Promoting 'organizations' of livestock keepers.*** A key aspect to promoting sustainable use is creating or strengthening structures to organize the keepers of animals and help motivate communal efforts (Kosgey & Okeyo, 2007). Organizations are stronger than individuals and can safeguard group interests better, by advocacy with authorities. In the longer term, building these structures may serve a capacity building role – allowing livestock keepers better access to information, strengthening their position in relation to extension services, facilitating the organization of training and improving bargaining power when marketing products. In Europe, there are strong farmer cooperatives and breeding organizations that go back a century and have also received much public support over the years.

2.3 Improving market access and promoting novel uses of animal genetic resources

Developing markets for livestock breeds, their products and services

The value of animal production can be increased by marketing products more effectively. Ease of marketing and lucrative prices for animals and their products can provide the biggest boost for continued use of animal genetic resources (Boxes 1 and 2). Development of niche markets is also important from the perspective of promoting sustainable utilization. Niche markets rely on creating perceived value regarding the conditions of production, product quality or a combination of these. Consumers that particularly value food quality or specific production methods are the most likely to purchase specialized niche products such as Parmigiano Reggiano cheese produced from Regianna cattle in Italy, high-value cured pork products from Iberian pigs reared in oak-forest production environments in Spain and meat from the black boned chicken breed in Viet Nam, known for its medicinal value. One of the ways to create demand for products of breeds reared in pastoralist systems with no chemical inputs is to market them as “range-fed” or “fed on natural vegetation”. Such products could also benefit from “geographical indication” recognition.

Box 1. Adding value to Nguni cattle

The Nguni of South Africa is an African taurine breed with a slight admixture of zebu blood that reached the region together with southward migrating pastoralists in about 300 AD. After white settlers arrived with exotic cattle, the Nguni cattle were long perceived as inferior because of smaller carcass size, non-uniform colour pattern and lack of information on their production potential. Even the people who had originally kept this breed started crossbreeding or keeping exotic cattle. Research in the 1980s then revealed that the Nguni breed is very tick-tolerant, can maintain its condition during seasonal food shortages, can obtain optimal nutritional value from the available forage, is a good walker and very docile. Its adaptation to harsh extensive production systems offers many advantages to smallholders. The Animal Improvement Institute has therefore initiated a project to supply selected Nguni bulls to smallholders together with training and infrastructural support. Nguni cattle have a wide range of colours. The colour variation indicates the cultural heritage of the breed, which has been raised by African stockmen for centuries. Colour variation frequently had a ceremonial and symbolic importance. The colourful Nguni hides are much in demand these days for pelts that are tanned with the hair on, for use as rugs, clothing and home furnishings. Being able to predict and generate specific colours has taken on a new economic aspect as these uses have recently increased. In addition, certain colours or pigmentation patterns (such as pigmented skin beneath white hair) can be helpful in adaptation of animals to harsh conditions of high solar radiation. All three of these factors (tradition, utility, adaptation) combine to make colour important for Nguni breeders, and unravelling the details of colour genetics can be useful for them (Köhler-Rollefson, 2004; Sponenberg, 2007).

In almost all areas of India, a niche market for local breed chickens and eggs, perceived to be “high-quality” and therefore more expensive, exists side by side with broiler chicken and commercial layer hen eggs. Similarly, in Malaysia, meat from the Kampong chicken is considered to be better tasting than the commercial breeds. In the United Kingdom, a ready market was developed for beef from Angus cattle as high-quality beef (with high marbling), which served to increase the Angus population. The measures adopted for this included promoting Angus beef through a restaurant chain. The fragility of some such niche markets is, however, demonstrated by the collapse of the restaurant chain following the outbreak of mad cow disease.

Box 2. Value-adding to peri-urban dairy farming in Latin America

Straddling the border of Peru and Bolivia, the Altiplano – a high-altitude plain at 4 000m above sea level – is one of the poorest regions in the world. At such high altitudes, the environment is unforgiving: drought and extreme cold are common. The region supports six million people, who mostly depend on agriculture. Potato is the staple but crop failure is a regular occurrence and many families live in extreme poverty. However, for some Altiplano farming families living close to urban centres, nutritional and income stability is not completely unattainable. Milk production is growing in importance in the region and a pilot project, under the ALTAGRO initiative of the International Potato Center (CIP) and its partners, has created a market in several large towns for cheese made from local cows' milk. Most households in the area earn around US$1 per day. With this initiative, dairy producers have more than doubled their income, with some now earning up to US$850 per year. The ALTAGRO project, financed by the Canadian Government, has supported the construction of two small dairies in Atuncolla-Illpa, a Peruvian town with a population of 10 000 people. A training plant set up at the experimental station of the Instituto Nacional de Investigación Agraria (INIA, Peru's National Agricultural Research Institute) is providing technical assistance to farmers and processors in how to transport the milk and process it into cheese (http://www.new-ag.info/07/04/focuson/focuson1.php).

Novel uses for animals and animal products

New uses have been developed for animals and their products with desirable consequences for continued maintenance of animal genetic resources. The unique immune system enhancement properties of Panchagavya (a mixture of milk, curd, ghee, urine and dung of indigenous cows prepared according to a recipe from ancient Ayurveda [Sushruta Samhita, 1985]), identified by new research (Chauhan *et al*., 2004) have led to new marketing possibilities in India and Sri Lanka. A non-governmental organization (NGO) in Rajasthan, India, has successfully introduced camel milk ice cream (desert dessert) as part of a comprehensive strategy to make camel rearing more profitable. Research in the United States of America on "aversive conditioning" using boluses with lithium chloride (Mueller, Poore and Skroch, 1999) shows that sheep can be trained to bypass the tender shoots of grapevines and trees for the weeds sprouting underneath.

Promoting use of animals in landscape conservation

Use of traditional grazing livestock for landscape heritage and biodiversity maintenance and for nurturing more complete ecosystems is a growing management practice in many developed countries. In the United Kingdom and Europe, and specifically the Balkans, the role of grazing livestock has been recognized as critical in the maintenance of wildlife and native plant biodiversity in many high nature value ecosystems. In the Mediterranean, grazing for shrub control helps to reduce forest fires. Cultural tourism associated with the unique culture of rearing local breeds has been expanding rapidly in Europe and also in South America where camelids are great attractions at parks and tourist sites. Similar approaches are needed in other developing countries, since here too particular breeds have shaped certain landscapes. Functioning pastoralist systems also have value as tourist attractions, besides contributing to ecosystem health.

2.4 Research and dissemination of research results

Public-funded applied research needs to focus on improving livestock rearing as an integral part of production systems and finding innovative solutions to real problems rather than on obscure theoretical topics. Successes as well as failures need to be published in order to capitalize on experiences. Research on the beneficial interrelationships between livestock and their environment and the necessity of livestock to maintain the sustainability of the landscapes they use is likely to provide enlightening results (Lewis, 2003). It is important to publish research results in accessible sources to ensure wider dissemination.

2.5 Promoting sustainability as the main objective

The supporting interventions should be such that they create an enabling environment to make livestock rearing self-sustained in the long term rather than dependent on outside support. If support is withdrawn due to a change in the macroeconomic situation or in the government, the livestock rearing system it has strengthened should not collapse. In fact, consequences of interventions could be tested against the potentiality that the support may be terminated.

Appropriate strategies for sustainable use will differ from country to country or among groups of countries because of the large differences among areas of the world, especially in terms of gross national product and available technology (Gandini and Oldenbroek, 2007).

3. GENETIC IMPROVEMENT AND SUSTAINABLE BREEDING PROGRAMMES

3.1 Introduction

The concept of sustainable use encompasses the development of animal genetic resources, ensuring that they remain a functional part of production systems, and the sustainable intensification of these production systems. Genetic improvement is the systematic exploitation of genetic variation in important traits among individuals within or between breeds. Breeding programmes for animal genetic resources are generally undertaken in order to improve their productivity and the quality of food and products derived from them and to ensure the availability of such food/products at affordable prices. Genetic improvement of livestock has made and will continue to make major contributions to agricultural development, food security, sustainability and livelihoods. In high-input production systems, which are common in the developed world, modern chicken and pig hybrids consume less than half the feed per kilogram of meat produced than the strains of 50 years ago. Such genotypes cannot, however, stand the harsh rigours (disease challenge, poor-quality feed, high temperature) of the low input, livelihood-focused systems in most of the developing countries. The high feed conversion efficiency has allowed the demand for meat of affluent societies to be met from a greatly reduced land area, thus releasing large areas of agricultural land that would otherwise have been required to produce poultry and pig feed. The importation of these improved genetics along with their associated production systems into developing countries has benefited consumers through availability of cheap broiler meat and pork and has also brought profits to farmers, although some other farmers were crowded out of markets because of these developments. There are other examples of benefits (with some qualifications) in the developing world. For example, the use of improved dairy genotypes has allowed the development of a large informal milk market that has dramatically improved smallholder livelihoods and human nutrition in the densely populated highlands of Kenya. A recent study has, however, shown that these animals are of higher milk potential than tropical climates and feed resources can support. In some situations, this resulted in drastic reductions in farmers' profits (King *et al.*, 2006).

Genetic improvement can take many forms, but generally and logically follows an ordered hierarchy of events. This starts with understanding of the production and marketing systems, choice of appropriate breeds or strains (sometimes resulting in replacement of existing breeds), establishment of an effective pure breeding or crossbreeding system, and then further improvement through selection of superior genotypes within populations that best suit the production and market conditions. The past 50 years have seen a drastic change in breed use. As a consequence, genetic improvement in the developed world is now primarily based on a few breeds and within-breed improvement. Almost all pigs in developed country markets are, however, crossbred and some strategic crossbreeding is being undertaken increasingly in cattle and sheep. In the developing world, most genetic change is taking place through change of breeds via crossbreeding programmes aimed at "grading up" of indigenous breeds towards exotics from the developed world. Systematic within-breed improvement is much less prevalent, although livestock keepers themselves continuously make decisions to keep and cull animals according to criteria they consider important. However, apart from a few cases, most of the structured breeding programmes have seen limited success, mainly because of inadequate understanding of the prevailing agro-ecological and marketing conditions.

3.2 Within-breed improvement

Within-breed genetic improvement programmes are routine for all the breeds and strains of livestock used in the dominant livestock production systems of the developed world. The genetic improvement typically accounts for 40 to 60 percent of the annual productivity gains in these systems. In the developing world, however, within-breed improvement to improve productivity is not common and has not often been sustainable. The relative lack of effort is partly due to the perception that greater genetic change is possible through the choice of specialized and improved exotic breeds and strains and crossbreeding systems. However, inadequately planned crossbreeding programmes have seen as much failure, if not more, as within-breed improvement programmes. Lack of suitable infrastructure, expertise and sustained government support has also hampered the establishment of within-breed improvement programmes in developing countries. Many factors have contributed to the lack of success in existing programmes – inadequate initial characterization of local populations, lack of participation of smallholder beneficiaries, inadequate dissemination mechanisms, inadequate or unsustainable infrastructure and expertise and/or rapid evolution of production systems (such as breed replacement), apparently eliminating the need or demand for the improved stock. Successful application of within-breed improvement is undoubtedly attainable in the developing world, but requires more careful assessment of demand, execution, delivery, impact and cost–benefit analyses.

Within-breed improvement presents a particular challenge in subsistence-oriented systems. It has to be based on adequate knowledge of the breeds in question and of the production system. Serious consideration has to be given to social, economic and environmental sustainability in this situation. Potential strategies for breed development appropriate to the local conditions and in keeping with the country's overall livestock development objectives should then be identified, assessed and prioritized (Box 3).

Box 3. Community sheep breeding programme in Peru

In the highlands of the Sierra Central in Peru (an isolated high mountain range environment at an altitude of about 4 000 metres above sea level), dual purpose Corriedale sheep and native-type sheep with different levels of exotic upgrading are kept in an extensive pastoral system. A survey conducted in 1996 identified three types of sheep production systems: individual family flocks, communal flocks belonging to villages and multicommunal flocks managed by cooperatives often involving several villages in a region. The survey identified two major requests of farmers related to breeding: the need for suitable rams and the need for training in breeding techniques. After extensive discussions, an interesting breeding structure based on the open nucleus concept was established and made functional. The land and labour necessary to run the nucleus were provided by the communities based on a series of arrangements and technical support was provided by the university. The nucleus was established by mating imported and locally produced top rams with 50 "best" females of each of nine communal and multicommunal flocks. Half of the ewes were returned pregnant to the suppliers and the other half were used for starting a central nucleus providing improved rams to communal and regional flocks, which in turn also provided rams to family flocks. Incidentally, the progeny of local rams proved to be better suited to the local market conditions than the progeny of imported rams. Farmer organization and farmer training are the backbone of this successful community-based sheep breeding programme, which is still in operation (Mueller, Flores and Gutierrez, 2002).

Generally, breeding objectives have focused on increasing productivity, often measured at the individual animal level. However, breed improvement should take into account the full range of attributes that make production systems sustainable. Selective breeding efforts can vary in scope from highly organized breeding programmes through to simple culling decisions based on individual phenotypic information under less controlled environments. The choice of methods will depend on the objectives of the breeding programme, their acceptability to the whole spectrum of stakeholders, access to improved genetic resources and the technology and infrastructure available.

In harsh mountainous or arid rangelands and pastoral systems where the environment and markets are unlikely to change in the medium to long term and where existing genotypes are well adapted, simple within-breed selection programmes focusing on as few traits as possible provide the best approach. The traits to be included need to be easily recorded for the animals to be selected and depend on the primary use of a breed. They will be multiple for multipurpose breeds. While natural selection will take care of many adaptive traits, fertility of male animals needs to be considered based on the results of a first mating season. When the environment and market requirements are changing, then more planning, better designs and institutional integration/coordination are required.

Where proper steps have been followed, successful within-breed improvement has been realized, even within indigenous populations in developing countries. The improved Boran cattle in Kenya, the Nguni cattle in South Africa, the Tuli cattle of Zimbabwe and the Murrah buffalo programme of India (with some limitations) are success stories in regions where many programmes have failed. What is unique about all these examples is that the production, policy and market environments were well understood, the locally available genetic resources/breeds were well evaluated and simple selection criteria agreed upon and implemented.

Intensive selective breeding will inevitably result in some reduction in genetic diversity within the breed. Systems for allocating breeding males to females based on the relative genetic contributions of parents have been developed to optimize genetic improvement while minimizing the rate of inbreeding (e.g. Sonesson and Meuwissen, 2000). These are used in commercial breeding and can be applied to local breeds if animals are appropriately identified and their pedigrees recorded accurately.

3.3 Choice of breeds and crossbreeding

The matching of appropriate breeds to evolving production systems has been a major contributor to growth in productivity and improvement of product quality in the developed world. This has been possible because developed world breeds and strains are relatively well characterized and are easily accessible through established processes such as genetic evaluation rankings and semen and breeding male distribution schemes. In the developing world, most animal genetic resources are inadequately characterized and access to animal genetic resources from other developing countries is often difficult or impossible. In fact it is ironic that recently developed well-intentioned instruments such as the Convention on Biodiversity may hamper the sharing of breeds across countries even if it appears to be the most technically logical option and would actually contribute to the maintenance of agricultural biodiversity. Unless livestock genetic resources of the developing world are better characterized and made more accessible, it is inevitable that the choice of breeds and strains for breed replacement and crossbreeding will be dominated by those of the developed world. This is evident, given the strong marketing strategies of the improved livestock genetics companies from the high-input systems of some developed countries. This may severely restrict the options of developing countries to develop their local breeds to meet goals for agricultural and economic development, sustainability and improvement of livelihoods.

With now widely predicted climate changes through direct and indirect effects (i.e. reduced number of growing days, hence herbage yields, increased disease outbreaks and challenges), the developing regions of the world's production systems are likely to be severely affected. Therefore, the need to source appropriate (those that best match the predicted future scenarios) breeds and genes from one developing country to another would be the most logical option. For example, if, as a result of global climate change, most of the sub-Saharan regions receive less rainfall and have hotter climates than currently is the case, then instead of embarking on long-term within-breed improvement of local breeds to match the predicted future environments in the affected areas, it would be better to access and move breeds. For example, Kenana and Butana cattle breeds of the Sudan that are already naturally adapted and reasonably productive under a harsh environment could be moved to those areas where harsher conditions are expected in future. Such realities add a new dimension to the potential utility of indigenous breeds.

In pastoral systems, and when market opportunities for improved milk and meat production exist but where large erratic environmental changes such as droughts are common, livestock keepers may maintain a range of diverse genotypes, some of which can survive drought conditions. Traditionally, pastoralists may keep a mix of species and breeds in their herds to maximize the advantages of good seasons and to reduce risk during bad seasons. For example, crossbred animals generated by crossing locally adapted females to an improved "exotic" breed male may be more profitable than their local purebred mothers when conditions are good, but may be the first to die when there is a bad drought. Farmers may use some indigenous breed sires and some exotic sires on parts of their herds/flocks while practising within-breed selection in part of the herd/flock. A good example is the Ankole cattle breed in the African Great Lakes region, where many keepers of large herds adopt a strategy of splitting their herds in this manner (Wurzinger *et al*., 2006). Better planning is then necessary to find a balance between high-profit/high-risk and low-profit/low-risk and to ensure a good bio-economic balance.

The use of crossbreeding has also made major contributions to productivity and product quality in the developed world. Structured crossbreeding systems, such as "terminal crossing" where first generation crossbred (F1) animals are slaughtered or where specialized crossbred dam lines are used, are common. Crossbreeding may also be used for gradual breed replacement with upgrading or the controlled maintenance of various proportions of exotics leading to formation of composites. The need to maintain pure breeds for the production of crossbred animals or commercial production is either managed by farmers or by commercial companies. Farmers have had extensive support and training and now understand the need to maintain a balance of breeds to make the system sustainable in the long term.

There are also examples of successful crossbreeding programmes in developing countries. In some situations, carefully conceived and executed crossbreeding programmes have merit as a rapid method of introducing desirable traits into local well-adapted breeds. The development of the Dorper sheep is one of the most successful programmes of composite breed development for a low-input production environment (de Waal and Combrinck, 2000). The breed was developed in South Africa by crossing Dorset Horn sheep with the fat-rumped, black-headed Persian sheep, a local Somali breed. Other successful crossbreeding programmes include the formation of the Sunandini synthetic dairy cattle in Kerala State, India (Box 4), the Boer goat of South Africa (Malan, 2000) and the Brazilian Milking Hybrid (MLB) cattle (Madalena, 2005). Crossbreeding has been most successful where it was followed by a rigorous selection programme involving livestock owners' participation and substantial public sector investment in the form of technical support. However, very often, crossbreeding has been indiscriminate and the local breeds that underpin the crossbreeding programme have been lost because of a lack of understanding by the authorities, companies and/or farmers involved that these pure breeds must be maintained to support the system. The strategic use of crossbreeding as a way out of a narrowed genetic base in commercial breeds is also considered important. It is gaining acceptance, for example, for fixing the increasing adverse trends in reproductive traits in commercial dairy cattle in North America. Such strategic crossbreeding is desirable to prevent long-term reduction of genetic diversity.

Box 4. The Sunandini cow in Kerala, India

Conditions in the State of Kerala in southern India are generally not conducive to classical dairy farming. These conditions are: the year round hot and humid climate, relentless pressure on land for human needs, acute scarcity of fodder, high rainfall and consequent mineral depletion of the soil. However, the Kerala dairy development programme, implemented over four decades (1964–65 to 2000–01), increased the State's average yield per cow per day from less than a litre to nearly 7 litres and milk production from 200 000 to 2.6 million tonnes per year. It has provided livelihood support to over one million smallholder households. The phenomenal growth in milk production can be attributed to a planned effort to develop the cattle genetically for milk production, supported by an extension programme for fodder development and a well-organized milk collection, processing and marketing system. A new composite breed, called "Sunandini" has been established by crossbreeding local cattle and further selection among the crosses. During the process, however, almost 80 percent of the local cattle have been converted to Sunandini and the local Vechur breed of cattle has almost been lost. The composite has a wide genetic base of exotic donor breeds – Brown Swiss, Jersey and Holstein Friesian and, to a lesser extent, the Indian donor breeds Sahiwal, Gir, Rathi and Kankrej. The Sunandini breed combines the positive qualities of local cattle such as adaptability, resistance to disease and strong hooves with the high production potential of the exotics. The level of exotic inheritance is limited to 50 percent. Its overall average lactation milk yield is 3 400 kg with a milk fat percentage of 4.0 (KLDB, 2004).

Finally, it should be recognized that large, highly variable and rich genetic pools of crosses between exotic and indigenous breeds exist in developing countries today. Such populations would serve as a quick foundation for synthetic breed formation; especially given the surviving individuals have the combination of genes that best fit the prevailing environments. Strategic use of such crosses to develop breeds for specific production systems is prudent and timely. For example, in trypanosomiasis endemic areas, it would make good sense to combine N'dama crosses that have survived and are productive with purebreds or crosses of equally tolerant cattle breeds such as the Orma Boran of Kenya and Sheko of Ethiopia (which is at risk). This underlines the importance of sorting out the problem of cross-country access to such genetics.

4. APPLICATIONS OF TECHNOLOGY IN GENETIC IMPROVEMENT

4.1 Current use of technology

Breeding programmes in the industrial production systems are complex and have evolved over many years of technical inputs in terms of design, determination of breeding objectives, calculation of economic weights, genetic evaluation methods, breeding strategies and delivery of services, as well as structures and techniques for dissemination of improved genetics. They involve the extensive use of technologies for data recording and storage, advanced computing and statistical analysis, reproduction, genetics and genomics. For example, dairy cattle improvement generally involves automatic milk recording of several hundred thousand cows each year, compositional quality assessment, data download to a central database, large computers and advanced computer algorithms that estimate the genetic merit of millions of animals simultaneously, artificial insemination of millions of cows and embryo transfer of several thousand cows, laboratory assays to determine parentage and, increasingly, molecular genetic testing to determine which animals carry particularly desirable sets of genes.

In the developing world, advanced technologies are more difficult to implement because of high cost, lack of expertise and infrastructure and are consequently not widely used. A contrasting situation, however, exists in some developing countries (such as India) where several top research institutes pursue the use of mainly molecular technologies for their glamour rather than for supporting a practical breeding programme. Research involving use of technologies is preferred over more tedious field research, which is perceived to be less rewarding. It is therefore necessary to ensure that simple breeding programmes based on proven genetic principles are not abandoned in favour of molecular genetic technologies that, in turn, need the existence of sound breeding programmes to be used effectively (see Box 5 for an example of effective use of advanced technology in a breeding programme in a developing country.) An example of effective use is that reproductive technologies, such as frozen semen or embryos, are used in several species to transfer germplasm between countries and sometimes to expand and/or disseminate rapidly an imported population. In addition to greater efficiency and reduced cost achieved, the use of such technologies greatly reduces the risk of disease transmission compared with importation of live animals.

Box 5. Marker-assisted introgression/gene introduction in India

A good example of a clear gene effect successfully implemented in a marker-assisted introgression (MAI) programme is found in India. The Booroola gene is being introgressed from the small Garole breed into the local Deccani breed that is suitable for meat production but has a limited reproductive performance. The Booroola gene has tremendous economic effects in this production system, increasing the weaning rate by nearly 50 percent. The breeding programme is undertaken by a research institute, but there are clear strategies and activities to ensure that the improved stock finds its way to shepherd flocks. Evaluation of the results in these shepherd flocks is an explicit part of the project, and initial results look very promising. Long-term impact, however, needs to be assessed. Early results also indicate that the litter size of Booroola carriers has a direct correlation with feed availability during mating/pregnancy. This means shepherds would be able to reap the benefits of the higher litter size during “good” years while the flock’s average litter size would not be unsustainably high during “bad” years. Shepherds may also like to keep a mixed flock of Booroola carrier and non-carrier animals as a risk insurance. MAI should not be ruled out for breeding programmes in developing countries, but should be assessed based on the merit of each case (van der Werf, 2007).

4.2 Progress with simple technology

The low level of use of advanced technologies in most aspects of genetic improvement in the developing world need not prevent effective improvement being achieved (Box 6). For example, a well designed improvement programme, based on selection of the best animals assessed on their own performance, with no other information or analysis, can achieve from 40 to 70 percent of the maximum possible rate of genetic improvement when compared with the use of all advanced technologies. The use of advanced technologies in the developed world is driven by the intense competition among breeding groups or companies and the desire to improve characteristics that are not easily or accurately recorded for every animal. In the absence of such intense competition in developing countries, there is no immediate need to introduce expensive, advanced technologies. A lower rate of genetic progress using simple cost-effective techniques is preferable and certainly better than no selection.

Box 6. Simplifying phenotypic measurement of performance

The marginal gain obtained by increasing the precision of information on phenotypic traits is subject to the law of diminishing returns. For this reason, developing countries that are attempting to implement an open nucleus breeding scheme may be advised to begin by collecting “low tech”, simple measurements of phenotypes from more animals and farms, rather than asking a few farmers to record complicated measures. For example, recording of milk yield could be bi-monthly or quarterly, rather than monthly. Lactation milk yield estimates based on only two test-days have been shown in some studies to have a correlation of greater than 0.85 with estimates based on ten test-days (Vasconcelos *et al*., 2004). Measurements of heart girth can serve as a proxy for body weight when scales are not available, as the traits are both highly heritable and highly correlated genetically (Janssens and Vandepitte, 2004). For traits such as overall likeability, temperament and general disease resistance that would be difficult or expensive to measure objectively, farmers can be asked to assign simple, ordered categorical scores for phenotypes.

The level of sophistication in terms of breeding strategies to be adopted in order to ensure sustainability and effectiveness needs to be carefully considered. It will depend on the state of the local infrastructure, the product market and available supportive technical expertise and institutional arrangements. An example of unsustainable levels of sophistication is the Kenyan

National Dairy Cattle Breeding Programme, with sophisticated progeny testing comprising multibreed centralized milk and butter fat recording and data processing systems involving several institutions. The programme was modelled along a European type of system without considering the local infrastructure and institutional limitations. The result is an ineffective system in which an unacceptably low (five or less) number of bulls per breed are recruited each year, with up to 11 years before the test results are completed, leading to a near-zero genetic gain. In this situation, a simpler nucleus-herd-based young bull scheme would have been more effective and sustainable, given the very limited number of herds actually contributing to genetic improvement. Location and management of the nucleus and recorded herds should ensure that production conditions in such herds match or mimic those of the smallholder and/or commercial farms under which most of the progenies of the bulls are raised.

4.3 Emerging technology applications

Reproduction, data and statistical analysis technologies continue to show regular incremental improvements and are expected to benefit but not fundamentally change the current design and operation of genetic improvement programmes. After decades of research and development, sexed semen has recently become available on a commercial basis (Johnson *et al*., 1987, Weigel, 2004). The use of sexed semen could be especially beneficial in countries such as India where religious beliefs preclude the consumption of beef. In such countries, the male animals are neglected and are a wasted resource. Technologies for management of female reproduction, such as synchronization of oestrus and (non) pregnancy diagnosis, can contribute to faster genetic improvement by decreasing the intervals between successive parturitions and increasing the number of candidates for selection.

Some technologies, such as the Livestock Identification and Trace-Back System (LITS) implemented in Botswana as a deterrent to cattle thefts (http://practicalaction.org/?id=peace5_cattle_tracking_botswana), could have huge potential for a genetic improvement programme where lack of individual identification is one of the main hurdles. The digital identification system uses radio frequency identification technology, is safe, environmentally friendly and tamperproof, and is used to identify individual livestock throughout the country. Other than managing cattle records and deterring cattle thefts, the system would also potentially open up access to important livestock markets such as the European Union (EU). The EU beef market regulation requires that imported beef be traceable from the export slaughter facilities to the individual animal that the meat came from.

Genomic technologies that have emerged from the human genome project are rapidly being developed for livestock. For example, in the past two years the ability to detect variations in the genetic code of individual cattle has risen from testing two or three variations in a single test to 50 000 variations in a single test, and the cost of testing has dropped more than a hundredfold (see Paper 2). Such technology developments are truly revolutionary and provide prospects for radical changes in genetic characterization and improvement. Several groups have already demonstrated that using such tests it is possible to determine the genetic merit of individual animals for most commercially important characteristics, without the need for any prior phenotypic information on the animal (Meuwissen, Hayes and Goddard, 2001). Huge quantities of molecular level data are, however, needed. The ramifications of this are still being explored, but it is clear that radical changes in design and operation of genetic improvement in the developed world could emerge. The ability to apply such technologies for routine genetic improvement in the developing world will require substantial reductions in cost, which seem likely to be achieved but cannot be guaranteed. However, it is already clear that these new technologies can be applied to achieve a much greater understanding of the functional genetic variation of developing and developed world animal genetic resources, which can then be used indirectly to better target genetic improvement globally.

4.4 Intellectual property issues

Virtually all the processes of relevant reproduction, data capture, statistical analysis and computing technology are in the public domain. Proprietary software is either readily available at reasonable cost or can easily be duplicated without infringement of proprietary rights. A small number of commercially valuable molecular genetic tests have been patented. In most cases these patents have not been registered in developing countries and therefore provide little or no restriction on use in developing countries. Coupled with the fact that such existing patents are for inventions with little practical value in the developing world, the willingness of patent owners to provide free or low-cost access to the developing world does not appear to have been tested. The recent development of high-throughput tests for genetic variants has led to several applications for patents for simultaneous use of large numbers of genetic polymorphisms. It is understood that in recent months the United States Patent Office has ruled that such patents are not valid and that the test for each polymorphism must be patented separately. The most likely consequence of this is that inventors will seek to protect such intellectual property (IP) by maintaining commercial secrecy rather than applying for thousands of separate patents. This will mean that the technology will be available to competing companies or countries, but the exchange of information will be hindered. It may also mean more difficulties for inventors to share IP with others, even where no commercial competition exists. This is because of the risk that key information might be leaked, thereby devaluing the IP. This situation is likely to be more damaging to technology use in the developing world where resources are less likely to be available to duplicate discoveries that have been protected by commercial secrecy.

5. CONCLUSIONS

Enhanced use and development of animal genetic resources in all relevant production systems play key roles in achieving food security and alleviating poverty. Ongoing utilization is also regarded as an effective means of maintaining diversity and ensuring the availability of resources for the future. Utilization is likely to continue if the breeds are perceived to provide genuine benefits – whether these are private benefits for the livestock keeper or public benefits for which society is willing to pay.

Continued increases in animal production and productivity will be necessary to enhance food security and provide critical income, products and services to hundreds of millions of poor families. Strategies involving incremental improvements in the production potential and productivity of traditional breeds, and corresponding gradual improvements in management and access to veterinary services, supplemental feeds and markets, appear most promising. The continued use of traditional breeds is likely to remain the most effective strategy for resource-poor farmers in many of the least-developed countries. However, opportunities may exist both to improve local breeds and for carefully managed and limited introductions of exotic breeds in areas of greatest production potential. These opportunities must be seized when genuinely available.

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CONSERVATION OF ANIMAL GENETIC RESOURCES: APPROACHES AND TECHNOLOGIES FOR *IN SITU* AND *EX SITU* CONSERVATION

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Summary

Livestock production faces major challenges through the coincidence of major drivers of change, some with conflicting directions: these are (i) an unprecedented global change in demands for traditional livestock products such as meat, milk and eggs, (ii) large changes in the demographic and regional distribution of these demands, (iii) the need to reduce poverty in rural communities by providing sustainable livelihoods, (iv) the possible emergence of new agricultural outputs such as bio-fuels making a significant impact upon traditional production systems, (v) a growing awareness of the need to reduce the environmental impact of livestock production, and (vi) the uncertainty in the scale and impact of climate change. This paper explores these challenges from a scientific perspective in the face of the large-scale and selective erosion of our animal genetic resources, and concludes that there is a stronger and more urgent need than ever before to secure the livestock genetic resources available to humankind through a comprehensive global conservation programme.

1. DARWIN, DYLAN AND EGG BASKETS: THE SCIENTIFIC CASE FOR CONSERVATION

The first of these papers has described the trends that are operating on animal genetic resources for food and agriculture throughout the production systems of the world. A much simplified summary is that livestock are a focal point for many drivers of change related to their ability to lift people out of poverty and into sustainable livelihoods, to satisfy global demand for livestock products and promote international trade, and the need for livestock production to reduce its impact on the environment and its contribution to global warming. A broad conclusion is that there will be a need for sustainable intensification of livestock production. The other papers in this series have indicated the scientific background of how this might be better achieved both now and in the future, and the needs for scientific information to support decisions on animal genetic resources.

The current drivers of change have led to a large number of breeds slipping between the cracks as production environments change, and change rapidly. Production environments are now shaped in part, to a greater or lesser extent, by the economics of the current global market, both for inputs such as feed and water for animals, and outputs such as meat, milk and eggs. Broadly, breeds survive if they are fit for the market conditions that prevail, and decline towards extinction if they are not, a parallel of Darwin and natural selection. The decline in numbers further increases vulnerabilities to other catastrophic events, such as conflict, disease, flood or drought. Box 1 examines the scale of erosion of the world's animal genetic resources using data from *The State of the World's Animal Genetic Resource for Food and Agriculture* (FAO, 2007) and concludes that as many as one in three breeds may be at risk of extinction, with a further one in ten already extinct.

Is this breed erosion a problem? Maybe not, if there is certainty and stability, but otherwise definitely yes. Unfortunately science tells us that, to quote Bob Dylan[††], "the times they are a-changin'" and that some of our past certainties may disappear. There is now an established scientific consensus that there will be a period of relatively rapid climatic warming over this century, and that human activity has contributed, and continues to contribute to this trend (IPPC, 2007).

Box 1. A brief review of breed erosion for mammalian and avian species based upon *The State of the World's Animal Genetic Resources for Food and Agriculture*

The Table below summarizes the risk status of breeds in 2006, taking the data presented in Tables 12 and 13 of section 1.B.5 of *The State of the World* report. At first sight it might be concluded that "only" one in five of all mammalian and avian breeds are "at risk" of extinction, although closer examination shows that only one in three can be viewed as "not at risk". The discrepancy arises from the "unknown" category.

	Mammalian		**Avian**		**Total**	
Risk Status	Number	%	Number	%	Number	%
Critical	255	4.6	245	12.2	500	6.6
Critical-maintained	59	1.1	20	1.0	79	1.0
Endangered	406	7.3	287	14.3	693	9.2
Endangered-maintained	160	2.9	55	2.7	215	2.8
At risk	880	15.8	607	30.2	1 487	19.7
Not at risk	2 129	38.3	521	26.1	2 650	35.1
Unknown	1 907	34.3	825	41.3	2 732	36.1
Extinct	643	11.6	47	2.3	690	9.1
Total	5 559	100.0	2 000	100.0	7 559	100.0

It is possible to throw some light on the true state of the "unknown" breeds by analysis of the information on breeds that were "unknown" in 1999 but for which more precise information is now available. Examination of Tables 19, 21 and 22 of *The State of the World* report shows that a total of 238 breeds were classified as "unknown" in 1999 and classified as either "at risk", "not at risk" or "extinct" in 2006. Of these 40 percent were "at risk", 57 percent were "not at risk" and 3 percent were "extinct". Using these figures as predictors of the true status of "unknown" breeds in 2006, the best estimates for all breeds in 2006 becomes 56 percent "not at risk", 34 percent at risk" and 10 percent "extinct", i.e. over one in three "at risk", a further one in ten "extinct", and just over one in two breeds "not at risk". A further point to note is that among the breeds known to be at "at risk", only one in five have some form of *in vivo* conservation measure in place. In conclusion, the position of global animal genetic resources is far from secure.

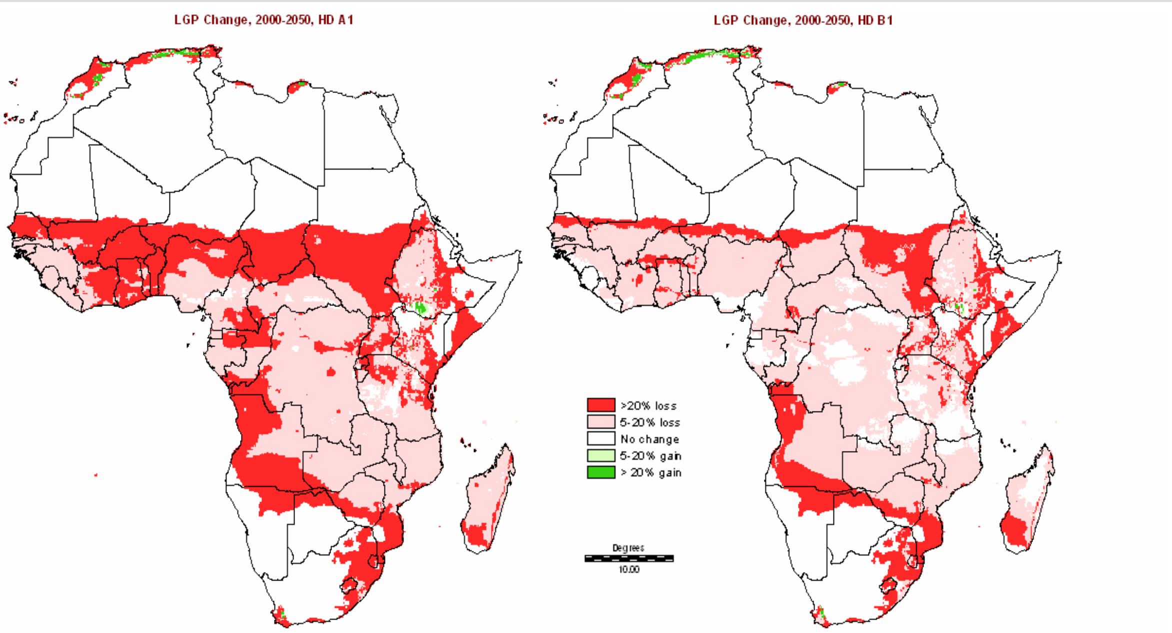
As an example, Box 2 shows the projected change in just one key agricultural parameter for one continent, the length of the growing season in Africa; other parameters such as the projected changes in the frequency and severity of droughts and floods are equally relevant. Box 2 illustrates an important additional point in that the degree of change and its agricultural and socio-economic consequences (see section 2.A.3 of *The State of the World* report for a brief overview of some of these) will depend on our future actions and their coordination on a global scale. These actions remain uncertain, but if they are limited or ineffective, more far-reaching consequences are expected. Further, as in all models, there are uncertainties resulting from limitations in our scientific knowledge and understanding: some scientists think the consensus position underestimates the extent of change, while others think the change is overestimated. Therefore, beyond the familiar uncertainties of market trends and the economic values of products, there is now an additional uncertainty of a magnitude and dimension that is beyond the experience of the modern world. In short, there is change rather than stability, with uncertainty writ large.

[††] Bob Dylan, 1963. The Times They Are A-Changin'. Popular Song.

As a consequence of these developments, the chances are higher than ever before that what may fit the needs of today may not fit the needs of our children's children. Science shows how the genetic diversity that we have within any of our livestock species today can be regarded as being partitioned between breeds and within breeds. Estimates of the magnitude of the diversity between breeds are well in excess of 50 percent of the total diversity for traits that are related to fitness for an environment (Cundiff et al., 1986). This leads to the inescapable conclusion that the between-breed component of diversity is very important for addressing a broad range of environmental conditions. The concern is that the breeds thriving today are primarily those fitted to high inputs and high outputs. Given uncertainty over the production systems that livestock will face in the future, for example the possible diversion of crops to biofuels, the breeds thriving today may not meet all our needs for tomorrow. Experience shows that we cannot change the genetic constitution of existing breeds rapidly enough to manage this uncertainty. Paradoxically, the ease of breed substitution which has placed so many breeds at risk is the primary reason why the *full* range of breeds we have today is so valuable for the future. There is a saying, "don't put all your eggs in one basket" and currently the world is moving towards a single basket of livestock.

Box 2. Scenarios illustrating the potential impact of global climate change on the length of the growing season in Africa, and the degree of uncertainty arising from differing assumptions

Brief descriptions of the scenarios are given in the notes below, but the two maps represent the extremes for this attribute taken from a range of scenarios considered by the authors. The colours, from deep red, light red, white, light green to green represent loss in excess of 20 percent, loss of 5–20 percent, change less than 5 percent, gain of 5–20 percent and gain in excess of 20 percent respectively.



Notes

1. Regions gaining 5 percent or more in the growing season occupy considerably less than 1 percent of the coloured regions for either map; examples of such regions in both maps are a minority of the coloured region on the North African coast, and to the south of the Great Rift Valley in Ethiopia.

2. The maps are derived using the Hadley Centre Coupled Model version 3. The 2 scenarios shown are: on the left, A1F1, assuming very rapid global economic growth, global population peaking mid-century, rapid introduction of new and efficient technologies, with an emphasis on fossil fuel energy; on the right, B1, assuming rapid change globally to service and information economies, global population peaking mid-century, introduction of clean and efficient resource technologies, with global planning but no new climate initiatives.

The maps are reproduced from *Mapping climate vulnerability and poverty in Africa*[4] by kind permission of P.K. Thornton.

The current state of insecurity of global animal genetic resources was discussed above. Global climate change might be anticipated to increase the insecurity of animal genetic resources, both directly through more extreme climatic events, even if the animal genetic resources appear well-adapted today, and indirectly through competition for essential resources such as food and water leading to an increased risk of conflict.

There is a stronger case than ever before for action to secure animal genetic resources through conservation measures. This case is based on managing the uncertainties in future food security, and extends beyond our raised awareness of the need for managing genetic resources and ecosystems that flowed from the Convention on Biological Diversity. The scientific logic is to develop and implement a global conservation strategy to create a secure backup, a "second egg-basket". This is a conclusion reached by at a meeting of experts in Montpellier (Gibson et al., 2006), and is one of the key action points identified by FAO in its *Global Plan of Action for Animal Genetic Resources*. The underlying operational science will be returned to later in the paper.

2. OPENING THE CONSERVATION TOOLBOX

Conservation can take different forms, depending on needs and resources. The major classification is whether or not the conservation is *in situ* or *ex situ*: the former describes a situation where conservation takes place in the environment in which the breed has been developed, and of necessity involves conserving live animals over generations. In contrast, *ex situ* conservation takes place outside the native environment. It may or may not involve live animals, as there is the possibility of storing gametes, sperm or oocytes, or cells with the potential to develop new animals, e.g. embryos, using the scientific advances of cryopreservation. There is a preference for *in situ* conservation, recognized by the Commission on Genetic Resources for Food and Agriculture (FAO, 1998a).

Why this preference for *in situ* conservation? The justification lies in the opportunity for the breed to continue to develop in its native environment, and in doing so the qualities that adapt it to the environment continue to be maintained through continued selection pressure. When the environment changes in one or more aspects, further selection builds upon an adapted foundation. Some adaptations, such as an ability to withstand drought or a resistance to a disease may be easily observed; others may be identified as part of the characterization process; others may be recognized unexpectedly and in crises. An illustration of the potential importance of *in situ* conservation is the North Ronaldsay sheep, native to the United Kingdom, which was habitually kept in an environment where seaweed was important component of its diet. Upon removal from this environment a large proportion of sheep died from copper toxicity. Further investigation showed that the ability to extract copper from the seaweed, with high efficiency, was an important adaptation of the breed to their native diet. If there had been no recourse to an *in situ* population, the surviving *ex situ* population would have been strongly selected *against* the very adaptation which had made the breed potentially unique!

Given the potential benefits of *in situ* conservation, why there is a need to consider *ex situ* measures? The immediate answer is that resources and commitment of farmers may not be forthcoming in the face of the pressures that have led to the need for the breed to be conserved, as it is seen as failing to meet the current needs. Alternative *ex situ* options are therefore necessary. These may include the establishment of live populations of the breed in institutional or NGO environments that may differ from the native environment, or by adopting cryoconservation. The choice of conservation options is not a strict dichotomy, as combinations of *in situ* and *ex situ* may be used. In particular, the idea of *in situ* populations supported by cryoconservation has become the method of choice in many developed countries.

Cryoconservation has a significant profile in livestock conservation. The development, refinement and practice of the associated cryopreservation techniques has been driven by the interest of breeding organizations in many livestock species, because of the improved genetic progress that can be achieved by using these techniques within breeding programmes. Nevertheless, while cryoconservation is a powerful option for conserving animal genetic resources, there are significant limitations: first, there are major differences among the livestock species in terms of the ease and effectiveness of applying the techniques (discussed further in section 3.6 of this paper); second, even in cattle where techniques are well developed success may be achieved only after a lot of time and resources, e.g. see Box 102, section 4.F.7 of *The State of the World* report and third, the cryopreservation of semen, oocytes and embryos requires the use of liquid nitrogen. Use of liquid nitrogen is not a universal option, as a significant number of countries have no, or only limited, experience of such procedures. Box 3 summarizes the information o this topic presented in *The State of the World* report[1] on this topic. It is clear that global conservation capabilities would be advanced if the capacity to use liquid nitrogen were to be made universal.

Box 3. A brief review of worldwide practice of techniques relevant for cryoconservation

The following is based upon data contained in section 3.D.2 of *The State of the World* report[1] on use of artificial insemination (AI), which is a more widespread technology and is and more widely applicable across the range of livestock species than embryo transfer. Only 84 percent of the 148 countries providing data report the use of AI in routine practice, and those not using AI were primarily situated in SW Pacific, Africa and Asia regions. However, this fraction is an upper bound on the routine use of liquid nitrogen, since AI may be carried out with fresh semen, rather than frozen, without requiring cryopreservation. Furthermore, whilst the use of AI may indicate capacity for storage and use of cryopreserved semen, it need not imply the routine use of procedures for collection and cryopreservation of semen, both essential for cryoconservation, as in many cases it was reported that exotic semen was being used.

Section 3.D.2 also demonstrates that the practice of AI is primarily directed towards cattle: whilst only one of the 84 percent of countries reporting use of AI fails to mention cattle, only 34 percent and 21 percent of countries report the use of AI for pigs and sheep respectively, the two next most common species for AI use. As with cattle, these figures are upper bounds on the fraction of countries that routinely collect, store and use cryopreservation for these species.

Conservation can be viewed as the creation of a gene bank containing live animals, or cryopreserved gametes and cells, or both. The gene banks secure the animal genetic resources, and in doing so provide new opportunities. One such opportunity is to enhance the exchange of animal genetic resources, and allow the benefits from animal genetic resources developed in one country to be shared elsewhere. Examples show that the importance of a breed can sometimes be more sustained in a country other than the one in which it is developed: for example the utilization of Sahiwal cattle (from South Asia) in Kenya.

3. SHARPENING THE TOOLS: THE CONTRIBUTION OF SCIENCE

This section will describe how science can help to make conservations more tractable and more effective, and how science currently under development can improve matters further. The basic integration of scientific approaches to conservation is described in the "Guidelines for management of small populations at risk" developed by FAO (1998a), which cover all activities relating to conducting censuses and compiling inventories, through considering what conservation options may be appropriate for a single breed, how actions may be prioritized, through to the technical guidelines on setting up and managing gene banks of live animals and cryopreserved gametes. The techniques for cryopreserved gametes were reviewed and updated more recently by the European Regional Focal Point for animal genetic resources (ERFP, 2004). This paper will only introduce and discuss areas where the underlying science has developed or where new conservation needs have been identified.

3.1 How many minutes to midnight?

To be effective, conservation needs to be timely. Preserving the gametes of the last dodo would have had little impact in terms of preventing the loss of the species. The proactive identification of breeds at risk for conservation actions is an important tool for monitoring animal genetic resources, yet it is a tool that remains blunt. One example is the identification of breeds that are at risk as a result of being confined to a small geographical area (a condition referred to as endemism), although they may be locally numerous. Such breeds may be at risk from catastrophic events. This was illustrated clearly in the United Kingdom during the foot and mouth disease epidemic of 2001. The regulations for controlling this disease within the European Union (EU) led the United Kingdom to cull livestock on a large scale, with the result that few individuals within the focus of the epidemic were left alive. Unfortunately, this focus closely coincided with the centre of population of the Herdwick sheep breed, which is numerous locally but restricted in its geographical spread. Recognition of the plight of this breed led to a number of emergency conservation actions during the epidemic. Quantitative measures of the risk associated with endemism have not been formalized. Risk may vary across regions; for example the area affected by a catastrophic drought may be wider than the area affected by a catastrophic fire. Thus, an assessment of the risk associated with endemism requires careful analysis of the potential impact of catastrophic events in the region in question. Attempts have been made (Gandini et al., 2004) to develop approaches to the calculation of risk status that are not merely functions of population numbers. Several such methods, of varying complexity, are in use, but these require further socio-economic and genetic inputs before they can be considered reliable. Limitations will remain – while it may be possible to obtain better data for quantifying some risk factors, such as the degree of cross-bred matings, other risks such as conflict may be harder to quantify objectively.

3.2 Turning safety nets into springboards

Conservation, particularly *in situ* conservation, has a dual purpose. It was introduced above as a "second egg-basket", a form of safety net. However, considerable socio-economic research has been carried out in an attempt to understand how this net can become a springboard for the return of a breed to the mainstream, in which no special measures beyond the market are required to maintain the population. In the FAO guidelines (1998a), the core approach to this transformation was establishing the true market value of a breed, emphasising the need to consider lifetime performance and lifetime contributions rather than simple measures of product yields under a regime conducive only to high outputs. This consideration and the options that exist for improving the recognition of full market value remain important. However, it is now widely accepted that a breed's value exceeds the expected market value of its products. Two further concepts can now be added to the valuation process to demonstrate this: first the contribution of a breed to managing climatic uncertainties and to recovery from environmental crises faced by farmers, and second the valuation of a wide range of potential non-market services. Box 4 illustrates why these concepts are important to maintaining breed populations and securing the livelihoods of farmers.

A more controversial area of economic science associated with conservation of live animals is the use of subsidy for maintaining breeds. An example of the complexity of this area is the mixed success of measures implemented by the EU, which has in the past supported such actions. While the subsidy halted the decline in census numbers of breeds covered by the scheme, there was a barrier to population growth caused by existence of a threshold population size (headage) below which a breed was considered eligible for subsidy: a trend existed for breeds to sit just below this threshold size for fear of losing subsidy. Therefore, subsidy is an effective safety net but an ineffective springboard! Consequently, subsequent EU support is more concerned with characterization and helping breeds to develop added values. This problem with headage barriers can also be faced by NGOs. One such example is the Rare Breeds Survival Trust in the United

Kingdom, which has re-vamped its qualifying conditions to allow it to act more effectively as a springboard for moving breeds beyond "at risk" status.

Box 4. Beyond the expected product value

Managing uncertainty. This can be illustrated by the considerable variation that exists between breeds in terms of their ability to withstand drought, which is empirically seen to be much greater than variation within breeds. Farmers in many regions rely on their livestock as a means of maintaining livelihoods through droughts. A breed providing this service may perform a more vital role than a breed that provides better returns in the good times but fails in the bad times leaving the farmer without support. Therefore, the valuation of a breed's performance needs to take account of the foreseeable crises that affect the production environment in which it is kept, rather than the average conditions. This process of valuation does not need to involve a straight choice between one breed and another: farmers in many regions recognize the benefits of maintaining a mixed economy of breeds, maintaining highly productive breeds to capitalize on the good times, while maintaining the robust breeds as insurance for the bad times. This latter role maintains populations, while securing livelihoods in the fullest sense of the word "secure".

Non-market values. Many products and services generated by livestock breeds are not marketed; these often include: transportation and traction; manure as fertilizer or fuel; fibre and skin for clothing; household meat, milk and eggs. Breeds may differ in their ability to provide these services. In addition livestock provide financial and socio-cultural services.

Financial services (Dorward et al., 2005) can depend on the animal having longevity in the environment in which it is maintained and retaining productivity in the harsher times of the production cycle. The ability to provide such services will clearly depend on the breed. Examples of financial services include:

- *buffering* (or consumption smoothing) whereby investments are made in livestock during periods when production or income exceeds consumption needs and then these investments are drawn upon later in the season when lower production and income are not sufficient to support consumption needs;
- *saving*, whereby animals are kept explicitly to provide for some major expenditure (such as a major purchase or investment, or expenditure on school fees or an important social activity);
- *insurance*, where animals are kept solely for the provision of insurance against unexpected events that either reduce income or require additional expenditure, such as accidents or illness; and
- *collateral* for borrowing.

Sociocultural services include important *social integration* functions in livestock keepers' society and culture. Traditional breeds may confer status on the individual owners, and may contribute to the sense of identity of whole communities through associations with traditional agricultural systems or landscapes, folklore, cuisine, ceremonies, and crafts[10]. It should also be kept in mind that commercial breeders gain status when their animals are priced or exhibited.

3.3 The genomic revolution

The genomic revolution with its tools of complete genome sequence, dense high-throughput genotyping at increasingly affordable prices, and rapid detection of genetic polymorphism are primarily new tools of characterization – to go from sequence to consequence. These developments will lead to an advance of an order of magnitude beyond our current understanding, are addressed in the companion paper. However, in the context of this paper, DNA has "traditionally" been used as the source of DNA markers with which to measure a genetic distance between breeds, or to measure genetic variation between and within breeds. These measures are then used to prioritize actions with a view to maximizing the diversity conserved (Eding & Bennewitz, 2007). There is an unresolved debate over the use of such methods, as there are sound arguments for basing actions on established and valued phenotypes rather than the measures based on anonymous marker DNA. One reason for basing actions on phenotypes is that empirically there appears to be a poor correlation between quantitative measures of diversity based upon phenotypes and molecular measures of diversity (Reed & Frankham 2001). A future outcome of the genomic revolution may be to improve this correlation through the richness of the information obtained with the new genomic tools. However if, as argued in section 1 above, there is a need to set in place a comprehensive global conservation strategy, rather than one led by a process of choosing among breeds, then the issues surrounding prioritization among breeds may become more academic.

3.4 Dealing in diversity

One of the perennial concerns of managing populations *in vivo* in conservation schemes has been the fear of inbreeding and the loss of diversity. Inbreeding is an unavoidable and natural process present in all populations, and as Bryson (2005) points out, to avoid all inbreeding in humans back to the time of Julius Caesar would require more humans than have ever lived! There are considerable scientific arguments to show that problems associated with inbreeding are related to the rate at which it occurs, not the observed degree, with faster rates associated with higher risks of genetic problems. This was addressed in the FAO guidelines (1998a), but science has continued to advance in this area. New techniques have shown how this rate of inbreeding can be managed simultaneously with maximizing selection opportunities under a range of circumstances. Combining these twin objectives is important for the management of breeding within conservation schemes, as populations may need to have deleterious genes removed, which is a form of selection, or may be part of a selection programme to improve their economic viability. The same core technique can be modified to minimize the rate of inbreeding given the resources available. Such techniques benefit from establishing the sires and dams of offspring each generation to build the pedigree. See Box 5 for more details. In summary, these techniques move breeders from contemplating a win–lose "trade-off" between selection gain and inbreeding, to taking advantage of a win–win by obtaining the maximum gain whilst managing rates of inbreeding.

Box 5. Managing rates of inbreeding in live animals

Breeding schemes may have conservation or selection objectives, but all schemes can be broadly classified into two groups: more sophisticated schemes with extensive pedigree recording and where genetic evaluations for selection are computed by combining information on a candidate and its relatives; and other schemes that are limited in their scope to accumulate full pedigrees on offspring, and/or rely on mass selection procedures. For the first group of schemes the sophistication of the scheme is sufficient to incorporate optimal contribution methods (Meuwissen, 2007) into selection procedures to manage rates of inbreeding. For the second group the rate of inbreeding can be managed with the use of a simple table, based on the ratio of number of breeding females to breeding males and the lifetime family size of a breeding female (Woolliams, 2007). The latter table is a more developed version of the T4.1 given in the FAO Guidelines for managing small populations at risk (FAO, 1998a).

Not all the issues of inbreeding are concerned with live animals: in cryopreserved gene banks the diversity "put in" limits the diversity "taken out". The diversity put in depends on how donor animals are sampled– both how many and which ones. In the event of a crisis, expending time considering this may be a luxury. However, there are established techniques for identifying which individuals from a breed should contribute, and the size of their contribution, in order to maximize the genetic variation that can be mobilized from the cryopreserved bank, even where there are constraints on the numbers sampled. These are most easily applied if pedigrees are available, using the same core technology as for conservation schemes using live animals.

3.5 Managing expectations from cryoconservation

In a cryopreserved gene bank there is no interest on deposits – you only get out what you put in, at best! This observation is central to the design of cryopreserved gene banks. Such banks require funds, effort and commitment to collect samples and to maintain them ready for a time of need, and it is vital that in the time of need the gene bank is fit for the purpose. The FAO guidelines

(1998a) introduced clear and valuable objectives for setting up gene banks as templates for others to develop and customize to specific needs. There are now examples (Roughsedge et al., 2006), such as the semen archive linked to the United Kingdom's National Scrapie Plan in which the sample numbers and sampling plan are linked to the objectives to be met in the future, *after* the semen is withdrawn from the bank. What was recognized by the FAO guidelines (1998a), and is now becoming more widely accepted, is that the amount of germplasm required for worthwhile objectives may be large and/or time consuming to acquire. It is essential that the managers of a cryopreserved gene bank recognize not only what the use of the stored material can achieve, but also what it *can't* achieve, as false expectations inevitably lead to poor strategic decisions.

3.6 Achieving more with less

It was already remarked in Box 3 that most use of cryopreservation techniques for breeding surrounds cattle, with little use in some other species. So it is to be expected that the effectiveness of cryoconservation of gametes and their use post thaw varies widely between livestock species. This is illustrated by Box 6, which is extracted from the FAO guidelines (1998a), which shows large differences between species in the time taken to collect sufficient semen to achieve the same package of measures defined by quantified outcomes from using the semen.

Box 6. The time taken to acquire sufficient cryopreserved semen for achieving the FAO "default" package of objectives for ten livestock species (see Note 1 below). The numbers of samples required for the package are defined by requirements after use post-thawing, i.e. what is ultimately achieved from using the semen.

		Days required to complete sample collection
Mammals	Buffalo	60
	Cattle	11
	Goat	3
	Horse	208
	Pig	123
	Rabbit	10
	Sheep	10
Poultry	Chicken	153
	Duck	191
	Turkey	492

Notes

1. The "default" package is detailed in Section 5.2.6 of *Guidelines for Management of small populations at risk (FAO, 1998a)* and includes semen for quantified sub-objectives involving re-establishment, supporting *in vivo* conservation, new breed development, and scientific research.

2. The numbers of samples required for the package are defined by requirements after use post-thawing, i.e. what is ultimately achieved from using the semen.

3. The times indicated are taken *Management of small populations at risk*[7], and are based upon leading technology current in 1998. While these times have been reduced for some species as a result of subsequent research, the large differences between species in required time will remain.

Furthermore, only for a minority of livestock species is it possible to routinely restore an animal with an intact genome of a breed produced entirely from cryopreserved material, i.e. an embryo, or cell, or gametes of both sexes. It is not yet possible in any poultry species. The relevance of this is that for those species where it is not possible, re-establishment of a breed from cryopreserved material must involve another breed and repeated backcrossing. Important incremental advances continue to be made in the broad range of cryopreservation techniques, partly through the pull of mainstream animal breeding seeking new opportunities. An example of notable improvement is the effective cryopreservation of oocytes in cattle. However significant and important challenges remain and some are listed in Box 7.

Box 7. Desirable advances in cryopreservation efficiency for the purpose of conservation

1. Reducing the scale of variation between species, exemplified in Figure 2, in the time taken to obtaining sufficient semen (or embryos) for delivering an identical quantified outcome post-thaw.
2. Developing a practical procedure to produce an intact genome of a poultry breed entirely from cryopreserved material.
3. Establishing reliable procedures in a range of species for obtaining thawed embryos for transfer that have little or no variation in the numbers of embryos per embryo (or oocyte) donor. Depending on the technique used for embryo or oocyte recovery this variation can be considerable and can create a serious lack of diversity in the resulting offspring. This is often ignored in simple formulae for number of embryos required, but the diversity “in” determines the diversity “out”!
4. Developing measures on semen pre-freezing to predict semen quality post-thaw. This would increase success rates per unit of stored semen, reduce numbers of doses stored and the reliability of outcomes post thaw. However the time taken to collect the semen might not be reduced.
5. Refining strategies for making best use of cryopreserved semen and embryos to re-establish extinct breeds (Boettecher et al., 2005). More rapid re-establishment would encourage more use of gene bank material in such cases.

One important new opportunity in conserving breed diversity is the potential use of somatic cell nuclear transfer (SCNT), leading to cloning (Wilmut et al., 1997). This is perhaps paradoxical, as cloning acts against diversity by creating individuals with identical genotypes! The explanation of this paradox is that the initial steps in the process involving the collection, preparation and storage of cells prior to nuclear transfer is a much more flexible technique, requiring fewer facilities, than the collection of gametes for cryopreservation (FAO, 1998b; Woolliams & Wilmut, 1999). FAO identified SCNT in 1997 as a viable option for emergency conservation actions where other more established techniques may be difficult to implement. Since then SCNT has been demonstrated in a wider range of livestock species, and its efficiency appears to be increasing in many parts of the world (Box 8). Given the developments in this field, the scope of application of SCNT and the recommended procedures for using SCNT in conservation actions should be reviewed and revised.

3.7 Ensuring best practice

The previous sections 3.1 to 3.6 have demonstrated that science continues to make important and valuable advances in sharpening the tools conservation more effective in achieving a diverse set of objectives. The state of the art in this area was drawn together in 1998 by FAO to ensure best practice, and some aspects of cryopreservation were reviewed by ERFP (2004). It would be timely to comprehensively refresh these guidelines.

Box 8. Somatic cell nuclear transfer and cloning

Somatic cell nuclear transfer (SCNT) was first demonstrated in sheep with the creation of Dolly by Wilmut and co-workers (Wilmut et al., 1997) in 1997. In principle, this technique allows the creation of large numbers of animals with identical genotypes, by transferring a nucleus from a donor cell into an enucleated oocyte to create an embryo for transfer. Since Dolly the technique has been demonstrated in several mammalian livestock species: cattle (1998), goats (1999), pigs (2000), rabbits (2002) and horses (2003). The technique has also been demonstrated in rodents, dogs, cats and ferrets, leading to the hypothesis that SCNT may be feasible for all mammalian species. It has yet to be demonstrated in any avian species.

Although much of the public's attention has been drawn to its potential use for commercial cloning on demand, SCNT has properties that make it an attractive proposition for use in conservation schemes. An outline procedure for use in conservation would be to collect tissue samples, e.g. skin samples from live animals, prepare the cells for culture and store. When required for re-establishing a live animal, the cells would be thawed and used for nuclear transfer to create an embryo that could be then cultured *in vitro* and finally transferred to a recipient animal. Neither the donor of the enucleated oocyte nor the recipient need be the same breed as the nucleus donor.

The strengths of SCNT compared to gamete or embryo cryopreservation are primarily in the collection and storage of material:

- The cost of equipment and training required for collection and initial treatment of tissue samples is comparatively low.
- Samples that have been given an initial treatment can be transported back to a central laboratory for further processing and cryopreservation over a relatively long time period, unlike the near-immediate and on-site cryopreservation required for gametes and embryos.
- In may be possible to recover and re-process cell lines after accidental thawing, providing this is identified early enough, unlike thawed gametes and embryos.

The weaknesses of SCNT are primarily in the use of the cells post-thawing:

- low efficiency of providing viable embryos; and
- increased risks of disorders at birth, sometimes fatal, associated with sub-optimal embryo culture procedures.

As early as 1997, FAO had identified SCNTas a viable technique for emergency conservation actions. Since then, the technique has been shown to be feasible in several livestock species, as described above, and there is anecdotal evidence that the efficiency of producing viable embryos free of disorders can be considerably increased with experience. In conclusion, it would be timely to review the potential of this technique and to integrate it more firmly into conservation guidelines. It may be that SCNT can only be recommended as a desired option for a few livestock species in special circumstances; however it may be worth considering the cryopreservation of somatic cells even for poultry on the assumption that advances in technology may eventually make nuclear transfer viable in avian species. Groeneveld (2005) proposed to create national genebanks on the basis of somatic cells.

4. MEETING THE CHALLENGE

In section 1, it was argued that there is a need to establish a comprehensive conservation strategy for animal genetic resources in the face of the global trends and growing uncertainties described in the first paper in this series. Experience has shown that securing animal genetic resources is best carried out proactively, giving time for the development of effective *in situ* conservation schemes wherever possible. This will not be possible in all cases, and securing the *full* range of animal genetic resources, as argued in section 1, will require the resources to provide a cryoconserved backup of all breeds. As identified in Box 3, such a strategy would require an extension of current capacities: cryopreservation techniques are not yet a global technology although routine in many countries, and species other than cattle would need to be addressed. There would be a need to refine the techniques for several species, with particular attention given to poultry. However, it is best to start now with current best practice rather than wait with animal genetic resources unsecured and at risk.

Coordination of gene banks will be needed either through multilateral or bilateral agreements. In this context, there is a need to resolve how cryoconserved material can be stored in duplicate (or more) locations, to reduce the risk of catastrophic failure of one; how access and use can be made timely and traceable, with appropriate security to manage disease pathogens; and how replenishment of the gene bank can be achieved after access and use. These aspects are discussed in the FAO guidelines (1998a) and ERFP guidelines (ERFP, 2004), but the principles contained therein need to be fleshed out. Of primary importance is the principle that such gene banks should encourage use – provided such use is equitable – as it is to the benefit of all.

Large-scale conservation cannot be achieved overnight for more than 7 000 breeds of domestic livestock! Operationally, in the face of the many drivers for change in what we require from animal genetic resources a strategy is required to capture the diversity these breeds represent, and to ensure that few, if any, slip between the cracks. Some components of this strategy can be suggested. As breeds are more likely to get lost in more rapidly changing systems, an initial step would be for institutions funding development programmes to be proactive in requiring project proposals to identify conservation needs, and to supply costed and timebound plans for addressing these needs that would be available for review and eligible for funding. Such plans would be easier to draw up and organize if they were to be based upon “default” packages of quantified sub-objectives for the cryopreserved material, such as that suggested by FAO (1998a), or successor guidelines, which may then be customized to meet particular needs, if appropriate. A further important step is to identify an ”emergency” package for geographically restricted breeds in the event of catastrophic events, such as drought and disease, and a fund for putting this into action when required. Such a package may require a range of options, including the collection of somatic cells, depending upon capacity in the affected area, the need and the time available. With these steps in operation, gaps in *ex situ* collections could be assessed to identify the need for further actions. None of these steps preclude the development of regional or national initiatives based on their own priorities.

5. CONCLUSION

Livestock production faces major challenges through the coincidence of major drivers of change, some with conflicting directions: these are (i) an unprecedented global change in demands for traditional livestock products such as meat, milk and eggs, (ii) large changes in the demographic and regional distribution of these demands, (iii) the need to reduce poverty in rural communities by providing sustainable livelihoods, (iv) the possible emergence of new agricultural outputs such as biofuels making a significant impact upon traditional production systems, (v) a growing awareness of the need to reduce the environmental impact of livestock production, and (vi) the uncertainty in the scale and impact of climate change. These challenges, with their inherent unpredictability, should be met by first securing the livestock genetic resources that are available to humankind.

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