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.

Résumé

L'inventaire des espèces et des races, la taille des populations, la distribution géographique et si possible leur diversité génétique, est en général le premier pas à accomplir dans un programme national pour la gestion des ressources génétiques animales pour l'alimentation et l'agriculture. Le principal objectif de ce genre d'évaluation est de documenter la situation actuelle en termes de connaissances sur la capacité de survivre et de se reproduire d'une population, ainsi que d'offrir des services aux éleveurs. Pour initier un inventaire il est nécessaire de disposer de certaines connaissances sur les points principaux et sur les attributions des caractéristiques. En outre, inventaire et caractérisation sont des procédures complémentaires étant donné que la caractérisation fourni l'information de base et les critères qui s'utiliseront pour établir et mettre à jour l'inventaire. Tenant compte que l'utilisation et la gestion des ressources génétiques animales sont des procédures dynamiques, le suivi d'une population doit être réalisé sur des bases concrètes. Pour cette raison, il est nécessaire de définir les indicateurs pour les situations de risque qui seront utilisés pendant le suivi tenant compte des différents points de l'inventaire et de la caractérisation.

L'article présente les méthodes et critères disponibles actuellement à partir de la recherche et des expériences passées pour classer, caractériser et suivre les ressources génétiques animales dans le but d'aider au développement d'un réseau plus efficace. Ont souligne en particulier les nouveaux outils et technologies. L'objectif de cette révision comprend toutes les espèces d'élevage ainsi que leurs ancêtres sauvages et les espèces sauvages voisines. Certains exemples se sont centré sur les bovins, ovins, caprins, porcins et volailles.

Resumen

El inventario de las especies y razas, el tamaño de sus poblaciones, su distribución geográfica y posiblemente su diversidad genética es en general lo que se hace como primer paso en un programa nacional para la gestión de los recursos zoogenéticos para la alimentación y la agricultura. El principal propósito de este tipo de evaluación es documentar la situación actual en términos de conocimientos sobre la capacidad de sobrevivir y de reproducirse de una población, y de proveer y producir servicios para los ganaderos. Iniciar un inventario requiere algunos conocimientos sobre los puntos de un inventario y la atribución de sus características. Por lo tanto, inventario y caracterización son procesos complementarios en los que el paso de la caracterización proporciona la información de base así como los criterios que se utilizaran para establecer y poner al día el inventario. La caracterización proporciona datos sobre el uso actual y potencial futuro de los recursos zoogenéticos en estudio, y establece cual es el estado actual de cada población de razas y situación de riesgo. Teniendo en cuenta que la utilización y gestión de los recursos zoogenéticos son procesos dinámicos, el seguimiento de la situación de una población debe llevarse a cabo sobre bases regulares. Por lo tanto, se necesitan definir indicadores sobre situaciones de riesgo para su utilización durante el seguimiento en base a los puntos del inventario y de la caracterización.

El articulo discute métodos y criterios disponibles actualmente provenientes de la investigación y de experiencias pasadas para inventariar, caracterizar y monitorear los recursos zoogenéticos, con vistas a asistir al desarrollo de una red mas efectiva. Se da particular consideración a las nuevas herramientas y tecnologías. El objetivo de esta revisión incluye todas las especies ganaderas y sus antepasados salvajes así como especies salvajes relacionadas. Algunos ejemplos se han centrado en bovinos, ovinos, caprinos, porcinos y especies avícolas.

***Keywords**: Descriptors, Relevant scales, Inventory, Characterization, Production systems, Phenotypic characterization, Molecular characterization, Genetic diversity.*

Conceptual framework

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

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.

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.

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.

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.

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.

Production systems and social organizations

As noted in the SoW-AnGR, 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.

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

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.

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[1] and Protected Designation of Origin[2], 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.

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

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 SoW-AnGR. It is important that countries are aware of what questions molecular tools can or cannot answer at

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[1]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.

[2]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.

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 coloured 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 organized to check the meat quality. The selection procedure for the Bresse breed has also been strictly regulated and is managed by a selection centre (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 Neuquén (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 Neuquén 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 Neuquén*". A study on the product's typical characteristics 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)

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 International Society of Animal Genetics (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 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.

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 SoW-AnGR, 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).

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).

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

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 agro-ecosystems. 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 north-western European breeds and the other with Middle-Eastern/southeastern European breeds.
Source: Peter *et al*. (2007)

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 eight 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.
Source: San Cristobal *et al.*, (2006).

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.

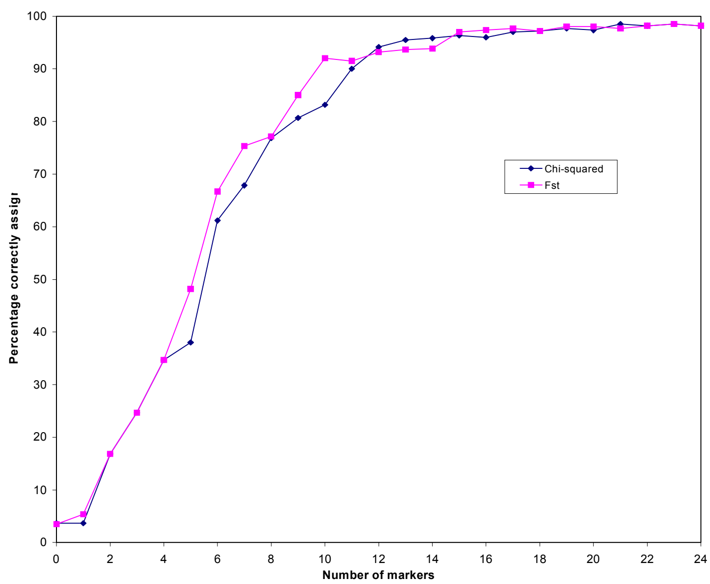

Figure adapted from Rosenberg *et al.* (2001).

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, which 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.

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.

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

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.

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.

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 SoW-AnGR 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 SoW-AnGR, monitoring can be an extremely expensive aspect of the management and should take as much advantage as possible of existing resources and activities.

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).

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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Panellists' comments and discussion

Mr Richard Clarke, Rare Breeds Survival Trust (RBST), United Kingdom

As the first NGO interested in the conservation of farm animal genetic resources we fully support the approach presented in this paper. Inventory, characterization, monitoring and utilization are the core principles that have driven the work of the RBST since its creation in 1973.

Since 1973, the RBST followed these principles for over 70 breeds of large livestock native to the United Kingdom. Since 1976, RBST has sought to share its awareness of breeds at risk through the publication of an annual watchlist. Eligibility is based on numerical, distribution and genetic factors. Over the past thirty years RBST has overseen the movement of 11 breeds from an "*at risk*" classification to mainstream.

Initially the Trust was independent of governmental agencies, but now is working more closely with them. Surveys of endangered breeds have been undertaken by RBST since 1976, but since 1994 the RBST, in close association with government agencies, has undertaken surveys of all livestock breeds in the United Kingdom. Surveys have been every 4–5 years.

In the past twelve months much of the work of the RBST has been encapsulated in the DEFRA (Department of Environment, Food and Rural Affairs) *UK National Action Plan on Farm Animal Genetic Resources*.

Finally, I would like to make a couple of observations concerning issues raised in this paper.

From the RBST's years of experience in considering breeds at risk of extinction, a preoccupation on numbers at the cost of an awareness of within-breed diversity, and geographical distribution can be dangerous.

This paper clearly demonstrates how technology is rapidly developing to allow us to better connect phenotype to genotype, but with it comes the threat that these technologies will allow more rapid selection for a specific phenotype, thus threatening genetic diversity.

Mr Milan Zjalic, International Committee for Animal Recording (ICAR), Italy
Animal identification and recording as tools in characterization of animal genetic resources

"*Characterization of AnGR encompasses all activities associated with the identification, quantitative and qualitative description, and the documentation of breed population…*" (*State of the World* report, Part 4 – Section B, Methods for characterization).

Identification and registration (I&R) are important tools at all stages of an animal's life, as well as in any part of the food production process such as:

- Farm and herd management.
- Animal recording.
- Animal breeding.
- Animal health and disease surveillance.
- Trade.

Animal marking is associated to the domestication of different animal species by humans. Identification techniques are classified according to characters used and to their permanence on the animal. Main artificial permanent systems are branding (hot-iron and freezing), tattooing, ear notching, ear tagging (metal and plastic) and electronic identification (injectable, ear tags and bolus), but natural systems are also used (mainly retinal imaging and molecular markers). Recent experience has shown that electronic identification in spite of its high-tech nature is the most suitable method of identification, also for developing countries. In this respect, the use of boluses for ruminants and injectables for monogastric animals are recommended. Molecular markers are routinely used in parentage registration.

Description and documentation of phenotypic characteristics of the breed population includes recording all traits of economic importance such as product yield, quality of products, longevity and reproduction traits. For decision-making on conservation strategies and on developments of breeds, it is necessary also to collect data on birth weight, age at sexual maturity, daily gain and others. Data should be collected, stored and processed in a uniform and standardized manner, so that they can be retrieved and compared with future data as well with data related to other local or mainstream breeds.

The International Committee for Animal Recording (ICAR) is composed of national and local organizations involved in animal identification, recording and genetic evaluation. The object of ICAR is to promote the development and improvement of performance recording and evaluation of farm animals through establishing definitions and standards for measuring animal characteristics having economic importance. Working together, Members of ICAR establish rules, standards and guidelines for the purpose of identifying animals, the registration of their parentage, recording their performance, evaluating their genetics and publication of such.

The present structure of ICAR as a registered non-profit INGO provides for full participation of its members in developing guidelines and recommendations on the basis of the sound scientific evidence. Guidelines represent minimum requirements set up to ensure a satisfactory degree of uniformity of recording among member countries and a maximum flexibility in the choice of methods. ICAR's logo – an antique Roman scale and inscription in Latin "*Quod scriptum est manet*" (what is written remains) symbolizes the message that one can measure animal traits using available tools and that data should be registered for future use. However, only standardized methods ensure uniformity of data and adequate evaluation of traits.

Animal identification, performance recording and genetic evaluation are of particular importance for the sustainable utilization of animal genetic resources and development of animal production in developing countries. For this reason, ICAR encourages and supports experts from countries with prevailingly low to medium input production systems in developing standards and guidelines suitable for their specific conditions. The ICAR Task Force Developing Countries promotes participation of experts from developing countries in ICAR research and training activities and promotes the establishment of country-specific identification and recording systems. Success stories, such as guidelines for buffalo milk recording, recommendations for animal identification and breeding programmes in low to medium input systems and activities of ICAR Members from developing countries in Africa, Asia and Latin America, indicate that this type of international cooperation is necessary also in support of conservation and sustainable utilization of local and endangered breeds.

Mr Jacob Wanyama, VETAID Mozambique/LIFE Network, Mozambique

The paper covers different levels and methods of characterization, and highlights the importance of covering more than only production. It provides details on the role of emerging technologies for molecular characterization. It provides a useful basis for conducting the inventory and monitoring animal genetic resources.

However, from the points of view of the livestock keepers:

- The breed definition does not give justice to the fact that many local breeds are products of deliberate manipulations by their keepers. It does not capture the selection criteria of breeders in the communities.
- Documentation methods should put more emphasis on the participation of stakeholders in the communities.
- If collecting materials for molecular characterization, those doing the inventories should obtain the prior informed consent of the owners of the animals!

The paper outlines what needs to be done. But it lacks information on transparent procedures on how the information is stored and used. It should be clear:

- Who has access to the data.
- Who can use them.
- How the data will be used.

The monitoring describes an early warning system. But again, it does not recognize the important role that livestock keepers can play in this process.

The future:

- NGOs have the direct contacts to livestock keepers in communities and therefore have the ability to aid communities in the inventory, characterization and monitoring of their breeds.
- The information collected should be stored in community-based and driven documentation centres. NGOs have the capacity to facilitate such process. They can build the capacity of communities to document their own breeds.

Summary of plenary discussion

The meeting was then opened for general discussion and interventions from the floor. Issues raised during this discussion included:

- The practical steps needed to improve inventory and monitoring.
- The need to ensure that results of characterization processes are widely disseminated.
- The need to consider legal issues – such as those related to intellectual property rights associated with methods for characterization and the animal genetic resources themselves.

The authors' responses and concluding comments included the following points:

- The need for a multi-disciplinary approach to characterization and for the appropriate allocation of roles in the characterization process.
- The importance of encouraging participation of breeders and livestock keepers and their organizations.
- The need for clear explanation of how the information gathered will be used, and for those that provide the information to be involved in the analysis and use of this information.

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.

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.

Résumé

On propose une utilisation durable des ressources génétiques animales pour l'agriculture et l'alimentation comme meilleure stratégie pour la conservation de la diversité. Atteindre l'utilisation durable permettra d'améliorer la qualité de vie et diminuera le risque à long terme de la survie des populations animales. Le concept d'utilisation

durable entraîne des mesures économiques, environnementales et socioculturelles. L'utilisation durable des ressources génétiques animales contribue aussi à la sécurité alimentaire, au développement rural, à l'augmentation des opportunités d'emploi et à l'amélioration des standards de vie des éleveurs. Soutenir l'amélioration des races à travers une meilleure infrastructure de services, de santé animale, d'opportunités de marché et d'autres interventions pourrait aider de façon significative à l'utilisation durable des ressources génétiques animales. L'utilisation durable comporte l'utilisation et amélioration des races qui possèdent des hauts niveaux d'adaptation physique aux principaux milieux. Cela comporte aussi l'application de principes génétiques adéquats au développement durable des races et à l'intensification durable des systèmes de production en soi. L'utilisation durable et l'amélioration génétique se basent sur l'accès à une large gamme de ressources génétiques.

Les programmes d'amélioration génétique doivent être considérés en termes d'agriculture nationale et développement des objectifs d'élevage, ainsi que compatible avec les conditions locales de moyens d'existence et d'environnement durable. L'amélioration génétique peut entraîner le choix de races plus appropiées, races plus pures adaptées ou un système de croisement de races et l'application de l'amélioration génétique à l'intérieur de la race elle-même. Le choix de la race et des systèmes de croisement de races dans les pays en développement a été un des facteurs qui a influencé le plus l'augmentation de la productivité et a bénéficier largement le fait que dans les pays développés les ressources génétiques animales soient bien caractérisées et puissent bénéficier d'un mouvement relativement libre. Là où les démarches appropriées ont été suivies à travers des évaluations correctes sur la demande, l'exécution, la remise, l'impact et l'analyse de coût-bénéfice, le succès de l'amélioration à l'intérieur de la race a tout de suite été atteint avec les population indigènes dans les pays en développement. Les objectifs d'amélioration et les programmes pour la subsistance et les systèmes de pâturage seront différents des programmes conventionnels. Les croisements de races ont eu plus de succès lorsqu'un programme de sélection rigoureux a été suivi et quand la participation des éleveurs et une partie du secteur public a été présente en forme d'investissement et appui technique. Dans tout programme d'amélioration génétique il est nécessaire de contrôler et faire un suivi de la consanguinité.

L'amélioration génétique de la race est une pratique normale dans le monde développé et est devenue une entreprise hautement technique qui met ensemble les domaines de la reproduction, le contrôle, l'identification et technologies du génome. Les nouvelles technologies du génome promettent dans un futur proche une meilleure capacité d'identification et l'utilisation et amélioration des ressources génétiques animales dans le monde en développement. Des systèmes utiles peuvent cependant être établis sans la nécessité d'appliquer des procédures ou des technologies à l'avant-garde.

Resumen

Se propone una utilización sostenible de los recursos zoogenéticos para la agricultura y la alimentación como mejor estrategia para el mantenimiento de su diversidad. Alcanzar el uso sostenible contribuirá a la mejora de la calidad de vida y minimizara el riesgo a largo plazo de la supervivencia de las poblaciones animales. El concepto de utilización sostenible conlleva dimensiones económicas, ambientales y socioculturales. La utilización sostenible de los recursos zoogenéticos también contribuye a la seguridad alimentaria, el desarrollo rural, el aumento de oportunidades de empleo y la mejora de los estándares de vida de los ganaderos. Apoyar la cría de razas a través de una mejor infraestructura, servicios, cuidados sanitarios de los animales, oportunidades de mercado y otras intervenciones contribuiría de forma significativa a la utilización sostenible de los recursos zoogenéticos.

La utilización sostenible comporta el uso y mejora de las razas que poseen altos niveles de adaptación de su forma física a los principales ambientes. También conlleva el despliegue de principios genéticos adecuados para el desarrollo sostenible de las razas y la intensificación sostenible de los sistemas de producción en sí mismos. La utilización sostenible y la mejora genética se basan en el acceso a un amplia gama de recursos genéticos.

Los programas de mejora genética necesitan ser considerados en términos de agricultura nacional y desarrollo de objetivos ganaderos, así como compatibilidad con las condiciones locales y seguridad de sustento y sostenibilidad ambientales. La mejora genética puede implicar la elección de las razas más apropiadas, la raza más pura adecuada o un sistema de cruce de razas y la aplicación de mejora genética dentro de la raza. La elección de la raza adecuada y de los sistemas de cruces de razas en los países en vía de desarrollo ha sido uno de los factores que más ha influido en el incremento de la productividad, y se ha beneficiado ampliamente del hecho que en los países desarrollados los recursos zoogenéticos están bien caracterizados y gozan de un intercambio relativamente libre. Donde se han seguido los pasos adecuados con evaluaciones correctas sobre la demanda, ejecución, consigna, impacto y análisis de costo-beneficio, el éxito de la mejora dentro de la raza ha sido alcanzado con poblaciones indígenas en países en vía de desarrollo. Los objetivos de mejora y los programas para la subsistencia y sistemas pastorales serán mayormente distintos de los programas convencionales. Los cruces de razas han tenido mayor éxito donde se ha seguido un programa de selección riguroso que implique la participación de ganaderos y parte substancial del sector publico en forma de inversión y soporte técnico. En todo programa de mejora genética es necesario controlar y monitorear la consanguinidad.

La mejora genética dentro de la raza es una práctica normal en el mundo desarrollado y se ha convertido una empresa altamente técnica que cubre los campos de reproducción, control, computo y tecnologías de genoma. Las nuevas tecnologías de genoma prometen la capacidad para identificar mejor y la utilización y mejora de los recursos zoogenéticos del mundo en vía de desarrollo en un futuro próximo. Los sistemas útiles pueden sin embargo ser establecidos sin la necesidad de aplicar procedimientos o tecnologías de vanguardia.

Keywords: *Targeting breeds, Production systems, Market access, Adding value, Dissemination, Sustainable breeding programmes, Technology, Intellectual property.*

Introduction

Sustainable use "*is the use of components of biological diversity in a way and at a rate 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 in Article 2 of the Convention on Biodiversity (CBD). *The State of the World's Animal Genetic Resources for Food and Agriculture* (SoW-AnGR) (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 SOW-AnGR, 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 (FAO, 2006a; FAO, 2008). 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 the first paper in this series, 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.

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).

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.

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.

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.

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.

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.

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).

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 (*www.new-ag.info/07/04/focuson/focuson1.php*).

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.

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).

Genetic improvement and sustainable breeding programmes

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.

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).

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

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).

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.

Choice of breeds and cross-breeding

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 cross-breeding systems, such as "*terminal crossing*" where first generation cross-bred (F1) animals are slaughtered or where specialized crossbred dam lines are used, are common. Cross-breeding 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.

Finally, it should be recognized that large, highly variable and rich genetic pools of crosses

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).

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.

Applications of technology in genetic improvement

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.

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.

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

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).

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.

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 companion paper on characterization). Such technology developments are truly revolutionary and provide prospects for radical changes in

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.

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.

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.

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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Panellists' comments and discussion

Mr Jan Philipsson, Interbull Centre, Sweden

This paper essentially concludes that the best strategy to maintain animal genetic diversity is based on the sustainable use of the AnGR. This is a pro-active way of considering the conservation issue and it includes economic as well as natural resource aspects, and has environmental and sociocultural dimensions. Interesting examples with diverse use of the AnGR are given as illustrations, primarily from developing countries.

In reviewing the options for the sustainable use of AnGR these may indeed vary considerably between developed and developing countries, due to differences in climatic challenges, resources and infrastructure. It is underlined that genetic improvement of livestock productivity in most cases is a prerequisite for sustainability and that production systems also will be intensified. It is an important task to investigate how this can best be achieved in different regions and production systems considering possible environmental impacts. However, intensification by such interventions leading to increased fertility, survival rate and health of animal populations would under many circumstances mean considerably higher productivity and less environmental stress.

The authors emphasize the need to make use of both traditional as well as new, molecular genetic tools to catch the opportunities for genetic improvement of livestock populations. However, they also point out that considerable improvements can be achieved already with traditional knowledge and rather simple techniques. They point for example to both the use of nucleus herd selection schemes and cross-breeding for the formation of composite breeds to improve productivity while maintaining adaptation to the environment. Effective use is thereby made of genes from different populations, a method that historically always has been practised in the dynamic forming of breeds. The proposed wider use geographically of tropically adapted breeds is important and should be further explored.

Obstacles for sustainable use of AnGR which I think need to be further addressed are:

1. Improper definitions of breeding objectives to be sustainable in relation to both market conditions and a broad range of traits in animals. This is still lacking in many populations of the developed world, and may lead to serious biological problems with the animals (e.g. declining fertility and disease resistance). In developing countries the choice of exotic breeds for use in pure-breeding and cross-breeding has too often not been properly assessed before embarking on breeding systems, that later proved to be non-sustainable, partly because of a lack of long-term breeding strategies.
2. The role of farmer involvement needs to be emphasized even more. There are neither short- nor long-term benefits of knowledge in genetics or animal breeding if this knowledge cannot be transferred to the farming community for their action. More research on this technology transfer issue and its proper consideration in development projects are needed.
3. There are generally too few trained animal breeding scientists and extension staff in most developing countries to effectively support implementation and running of sustainable breeding programmes. Also in the developed countries there is a shortage of quantitative geneticists needed for development of AnGR. Increased research supporting the sustainable use of AnGR and intensified capacity-building is therefore necessary.

In conclusion, this paper emphasizes the sustainable use of AnGR as the best method to maintain necessary genetic diversity. For that to happen, I would like to emphasize that genetic improvement programmes are greatly dependent not only on genetics, but also on policy, organizational and infrastructural issues to be sustainable.

The issue of short-term vs. long-term benefits of genetic improvement programmes was raised. It was stated that it simply takes too long for the benefits to be visible.

My answer to this is that the time it takes to see the results of genetic improvement programmes depends very much on the species, breeding strategies chosen and the production system. For species with short generation intervals, such as poultry and pigs, results of both pure-breeding and cross-breeding are realized within one to two years, whereas effects of within-breed selection of dairy cattle takes five to ten years if germplasm from other more productive strains of the same breed cannot be used. On the other hand, all genetic effects are accumulated for each generation of selection. The later you start a selection programme with a breed, the more it will fall behind other breeds under continuous selection. However, genetic improvement can be achieved much faster through cross-breeding with a superior breed assessed to be suitable for the environment in question, and provided that a long-term strategy has been worked out and considered feasible. In many cases such a strategy ends up with a new synthetic breed as the authors of this paper have indicated.

The other point I would like to raise on this issue, and which has an impact on the outcome, is that genetic improvement programmes should not be seen in isolation. First of all they must be applicable to the prevailing environment and production systems. Secondly, improvements in management and feeding must also be made, and some of these improvements may be realized even before the genetic ones. A holistic view of an improvement programme must be aimed for, where the genetics is just one component, but an important one. Whatever the strategy chosen, a long-term perspective must always be taken.

Mr Raúl Perezgrovas, Instituto de Estudios Indígenas, Chiapas, México

I would like to thank FAO for the invitation to be a panellist during the Scientific Forum, and for the opportunity to share some comments on the paper on "*Sustainable use and genetic improvement of Animal Genetic Resources*". I would like to congratulate Chanda and the co-authors of the paper for the comprehensive coverage of such a wide number of topics regarding the sustainable use of AnGR.

I have been requested to present some reactions, and, as an animal scientist I can easily relate to all of the strategies and technical approaches presented by the different authors. It was possible to identify the key words, as they were constantly mentioned throughout the document, and some of them were:

- Animal genetic resources.
- Farm animal breeds.
- Livestock.
- Breed improvement.
- Genomic technologies.
- Animal productivity; to mention just a few.

However, as a social scientist, I noticed the low frequency in the use of "*other*" key words, such as:

- Livestock keepers.
- Small-scale farmers.
- Livelihoods.
- Local knowledge.

And this is very important when the topic under discussion is precisely the "*sustainable use and genetic improvement of AnGR*", because we know that sustainability has a social, an economic and a cultural component.

So, I present here a couple of suggestions to be considered by the agricultural technicians, the extension workers, the university professors and researchers, and the policy-makers.

First, we all need to take a more humble approach and recognize that livestock keepers can teach us a few things regarding the sustainable utilization of farm animals; it is they who have conserved and improved many indigenous or local animal breeds, making them a vital part of their livelihoods.

And second, there are many participatory methodologies that will allow the livestock keepers and the researchers, and the policy-makers to undertake a fruitful learning experience for all.

There is in the paper a very good example of how to integrate the local peoples' expertise. When talking about "*capacity-building and training*", I came across the following statement, and I quote:

> "*…training should build upon existing knowledge of the production system, and enable livestock keepers to make informed decisions…*"

I would suggest that the same spirit is considered also when we speak of genetic improvement, promoting novel uses of animal genetic resources, and the design of sustainable breeding programmes.

Earlier today, the issue of Livestock Keepers' Rights was raised as necessary in a global action plan. I suggest that the issue of "Listening to Livestock Keepers' Voices" needs also to be discussed.

Ms Xuan Li, South Centre, Switzerland

First of all, I would like to extend my appreciation to FAO for inviting me to be a panellist today. I represent the South Centre, an intergovernmental organization and think tank of the developing countries, with its headquarter in Geneva, Switzerland. The member states of the South Centre comprise G-77 and China. Our mandate is to provide strategic vision and technical support for the developing countries, particularly in the field of intellectual property, trade and global governance.

Coming to the paper, sustainable use and genetic improvement is considered one of four strategic components of the *Global Plan of Action for Animal Genetic Resources*. The paper properly demonstrates that there is no inherent incompatibility between conservation and utilization if animal genetic resources are properly managed. The immediate questions arising are, what are the challenges and what management strategy will work?

Before addressing the challenges, I would like to give a brief picture on what is happening in major international fora in the field of animal genetic resources in Geneva. In WIPO-IGC (World Intellectual Property Organization Intergovernmental Committee on Intellectual Property and Genetic Resources, Traditional Knowledge and Folklore), the issue is rather limited to the discussion of plant genetic resources, and no binding international agreement has been achieved. In WTO (World Trade Organization), the matter is overshadowed by the debate on "*disclosure of source*" and "*prior informed consent*". In WHO (World Health Organization), emphasis has been made to urge member states to establish mechanisms that ensure the routine and timely sharing of biological materials and isolates from both humans and animals, and no proper benefit-sharing scheme is available. In short, neither effective incentive to promote sustainable use of animal genetic resources nor proper international regulation on genetic resource protection has been provided.

Reading from the paper, in my view, there are at least four challenges that we are facing to ensure a sustainable use of animal genetic resources. The first challenge is to re-think livestock sector policies that "*distort the playing field*" on which indigenous breeds compete. As we have seen, farmers are often disadvantaged by subsidies on feed, artificial insemination and other inputs that tend to favour exotic breeds. From a policy perspective, there is a need to conduct some systematic policy analysis to assess the implications of the existing livestock policies, and respond accordingly.

The second challenge is, from an economic perspective, that appropriate incentive and funding mechanisms to foster innovation is crucial. Choice needs to be made between patent and alternative mechanisms, whichever is more cost-effective to foster sustainable use and innovation.

The third challenge is that the interface between animal genetic resources and intellectual property (IP) seems to be underestimated. The statement "*all the processes of relevant reproduction, data capture, statistics analysis, etc are in the public domain*" is inaccurate. In addition, a range of rapidly developing molecular and reproductive biotechnologies also has important implications for animal genetic resources management. In order to ensure a sustainable use of animal genetic resources, efforts must be made to carefully examine the interface between animal genetic resources and IP.

The fourth challenge is that a proper scheme to ensure access to animal genetic resources and technology transfer as well as benefit-sharing is necessary. Specifically, there is a strong need to establish an international binding treaty to stimulate the sustainable conservation and use of animal genetic resources. Such a treaty should cover "*any genetic material of animal origin of actual or potential value for food and agriculture*". The objective should target the conservation and sustainable use of animal genetic resources for food and agriculture and the fair and equitable sharing of benefits derived from their use, in harmony with the Convention on Biological Diversity, for sustainable agriculture and food security. The International Treaty on Plant Genetic Resources for Food and Agriculture serves as an excellent analogy. Considering the slow movement in WIPO, WTO and WHO on genetic resource discussion, Member states are encouraged to work towards the establishment of an efficient, effective and transparent multilateral system at FAO, to facilitate access to animal genetic resources for food and agriculture, and to share the benefits in a fair and equitable way.

To conclude, if properly managed, a global action plan for animal genetic resources will be a major contribution to the implementation of the Convention on Biological Diversity in the field of food and agriculture. Efforts should be made to establish a series of coherent policy and legal regimes to achieve the purpose above.

Summary of plenary discussion

The meeting was then opened for general discussion and interventions from the floor. Key issues raised during this discussion included:

- The need to reinforce research, human resources and institutions, particularly in the developing world.
- The significance of buffaloes in the context of South Asia and the limited attention that this species attracts from international donors and researchers.

- The need to better utilize existing technologies and not always rush to adopt new technologies.
- The importance of characterization as an element in the process of promoting sustainable use – for example in the identification of breeds with specific attributes such as disease resistance.
- The need for information on breed characteristics to be effectively disseminated.
- The problem of reconciling the short-term needs of farmers with the longer-term objectives associated with sustainable utilization.

Responses and final comments of the authors included the following points:

- Better understanding of animal genetic resources is vital to achieving sustainable utilization.
- Existing knowledge, including local knowledge, needs to built upon and better integrated into management strategies.
- Community-based structures are the building blocks of sustainability.
- In addition to North–South collaboration, South–South cooperation in the utilization of animal genetic resources is needed.
- Ensuring sufficient resources for the management of animal genetic resources requires better awareness of the importance of livestock production.
- There are links between the utilization of crop and animal genetic resources, and research efforts in the two fields can be complementary.

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:
1. An unprecedented global change in demands for traditional livestock products such as meat, milk and eggs.
2. Large changes in the demographic and regional distribution of these demands.
3. The need to reduce poverty in rural communities by providing sustainable livelihoods.
4. The possible emergence of new agricultural outputs such as bio-fuels making a significant impact upon traditional production systems.
5. A growing awareness of the need to reduce the environmental impact of livestock production.
6. 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.

Résumé

La production animale se trouve face à des défis importants dus à la coïncidence de différents facteurs de changements, certains en évident conflit par rapport à leur orientation. C'est-à-dire:
1. Changement sans précédent de la demande au niveau mondial de produits traditionnels tels que la viande, le lait et les œufs.
2. Changements importants dans la distribution démographique et géographique de la demande.
3. Le besoin de réduire la pauvreté dans les communautés rurales en offrant un moyen d'existence durable.
4. L'émergence due à la possibilité de nouveaux produits de l'agriculture tels que le combustible biologique qui a un impact significatif sur les systèmes traditionnels de production.
5. Une majeure considération de la nécessité de réduire l'impact environnemental dû à la production animale.
6. L'incertitude sur le niveau et l'impact du changement climatique. Cet article étudie les défis du point de vue scientifique dans le cas d'une érosion sélective des ressources génétiques animales à large échelle. En conclusion, il existe plus que par le passé l'urgence d'assurer la disponibilité des ressources génétiques animales pour l'utilisation humaine à travers un programme mondial de conservation.

Resumen

La producción ganadera se enfrenta con importantes desafíos debido a la coincidencia de varios factores de cambio, algunos de los cuales en claro conflicto con respecto a su orientación. Estos son:
1. Un cambio sin precedentes en la demanda a nivel mundial de productos tradicionales tales come la carne, la leche y los huevos.
2. Importantes cambios en la distribución demográfica y geográfica de la demanda.
3. La necesidad de reducir la pobreza en las comunidades rurales ofreciendo una renta sostenible.
4. La emergencia debido a la posibilidad de nuevos productos de la agricultura tales como el combustible biológico que tienen un impacto significativo sobre los sistemas tradicionales de producción.
5. Una mayor conciencia de la necesidad de reducir el impacto ambiental debido a la producción ganadera.

6. La incertidumbre sobre el nivel y el impacto del cambio climático. Este artículo estudia estos desafíos desde un punto de vista científico en el caso de una amplia escala y erosión selectiva de los recursos zoogenéticos. En conclusión, existe más que nunca una fuerte y mayor urgencia de asegurar la disponibilidad de recursos zoogenéticos para uso humano a través un programa mundial de conservación.

***Keywords**: Cryoconservation, Breed erosion, Climate change, Genomic revolution, Managing uncertainty, Inbreeding, Somatic cell nuclear transfer (SCNT).*

Darwin, Dylan and egg baskets: the scientific case for conservation

The first of this series of 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, 2007a) 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[1], "*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).

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.

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

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

Box 1. A brief review of 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 Part 1 – Section 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

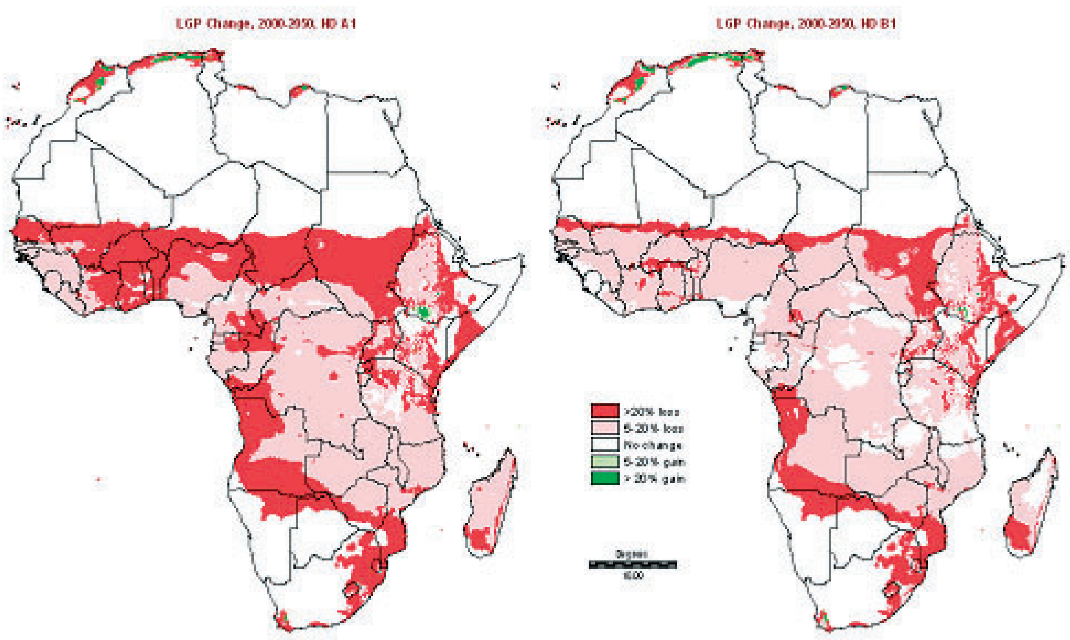
It is possible to throw some light on the true state of the "unknown" breeds by analysis of the information on breeds that were "unknown" in 1999 but for which more precise information is now available. Examination of Tables 19, 21 and 22 of *The State of the World* report shows that a total of 238 breeds 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.

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.

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

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* by kind permission of P.K. Thornton.

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* (FAO, 2007b). The underlying operational science will be returned to later in the paper.

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 following sections 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 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.

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.

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.

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

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.

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.

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, emphasizing 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.

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

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.
- *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. It should also be kept in mind that commercial breeders gain status when their animals are priced or exhibited.

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 previously 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.

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.

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.

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

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).

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.

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.

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. This is not yet possible in practice for 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. Examples of notable improvement are the effective cryopreservation of oocytes in cattle, and the ability to collect and cryopreserve epididymal spermatozoa in several species. The latter adds a back-up tool of collecting male gametes from abattoirs, but such a course of action must not risk breeding males or potential breeding males of a breed at risk.. However significant and important challenges remain and some are listed in box 7.

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.

Ensuring best practice

The previous sections 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.

Meeting the Challenge

Previously, 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 previously, will require the resources to provide a cryoconserved backup of all breeds. As

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 from *Guidelines for management of small populations at risk*, 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.

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

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

1. Reducing the scale of variation between species 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.

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.

Conclusion

Livestock production faces major challenges through the coincidence of major drivers of change, some with conflicting directions. These are:

1. An unprecedented global change in demands for traditional livestock products such as meat, milk and eggs.
2. Large changes in the demographic and regional distribution of these demands.
3. The need to reduce poverty in rural communities by providing sustainable livelihoods.
4. The possible emergence of new agricultural outputs such as biofuels making a significant impact upon traditional production systems.
5. A growing awareness of the need to reduce the environmental impact of livestock production.
6. 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.

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.

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Panellists' comments and discussion

Mr Arthur Mariante, EMBRAPA Genetic Resources and Biotechnology, Brazil

A very interesting paper, which brings back the old question: *in situ* or *ex situ*, with a different approach! John and his co-authors brought some new ingredients to this subject. Some of their core messages are:

- Diversity "put in" limits diversity "taken out"!
- How many and which ones to include?
- Gene Banks pay no interest! You get out only what you put in!
- What the use of the stored material can or cannot achieve?
- Use of SCNT for emergency conservation actions.

I would like to demonstrate some aspects of animal genetic resources in Brazil.

Most livestock are not indigenous to Brazil; animals were brought in by the settlers, have been submitted to natural selection, and supported animal production in the country for centuries. At the beginning of the twentieth century, exotic breeds were imported and gradually replaced these adapted breeds.

To avoid the loss of this genetic material, in 1983 Embrapa decided to include conservation of animal genetic resources among its priorities. At that time, we decided to conserve those old breeds both ways, as suggested by John: *in situ* and *ex situ*. We agree with the authors that there is no dichotomy, and these two methods complement each other.

In situ conservation is carried out in nucleus herds (conservation nuclei), maintained in the habitats where the breeds have been naturally selected.

When there are human and physical resources in the nucleus, the collection and freezing of genetic material are carried out *on farm*. When it is not

Figure 1. Ex situ *conservation - Semen and embryos are stored at the Animal Germplasm Bank located at our Experimental Farm located in Brasilia. 65 000 semen samples and 250 embryos are being stored at the Animal Gene Bank (AGB), located at the Experimental Farm. More than 8 000 DNA samples are being stored at the DNA Bank.*

possible, some animals are temporarily transferred to the Experimental Farm for this collection.

We agree with the conclusions by the authors, when they list six major challenges that livestock production is facing nowadays. The mentioned unpredictability of these challenges should really be met by securing the animal genetic resources that are available to mankind.
This task should be shared by countries that have the facilities and human resources to do so, building capacities in regions where this is not yet being done.

The time may have arrived to establish regional gene banks, a huge project postponed by FAO in the early 1990s, due to different animal health legislation of countries within the same regions. The establishment of subregional gene banks could be the way to proceed in order to save endangered breeds of countries that are not yet prepared to do so. We are all responsible!

Ms Nitya S. Ghotge, ANTHRA, India

While on one hand the paper states that the position of global animal genetic resources is far from secure, it does not adequately address the relative merits and demerits of different approaches and technologies with reference to different nation states, which then brings one to the very crucial question of who will conserve the genetic material, where and how. The paper also does not touch on the very important aspect of the ownership of genes and genetic material.

Currently, the genetic diversity of domesticated livestock lies in the Southern, lesser-developed countries, often with farmers living in fragile and marginal livelihoods. Efforts to preserve this diversity must go in tandem with efforts to improve the livelihoods of these farmers, and this is where funds need to be channelled. The ownership of the genetic material must remain with the communities and not in the private hands of industries or institutes.

Our organization ANTHRA which is based in India works with small and marginal farmers – dalits, adivasis (indigenous communities), pastoralists and landless groups – especially with women from these marginalized communities. Our work focuses on production and farming systems, and within them the crops and fodder varieties, livestock and plant genetic resources, medicinal plants and health care traditions, land and water use, and the indigenous knowledge connected with these systems.

We support viable community-based livelihood-enriching interventions which use and strengthen peoples' knowledge systems in productive ways and make them less dependent on external forces. Towards this end we have been active in supporting local livestock production systems such as women and backyard poultry with a special focus on the Aseel, Nicobari and Kadaknath breeds; local goats –the Kanchu Meka breed; local cattle – the Dangi; and local pigs – the Nicobari for different adivasi (indigenous) communities, and the Deccani sheep for pastoral communities.

Mr Shakeel Bhatti, FAO International Treaty on Plant Genetic Resources for Food and Agriculture, Italy

Thank you, Mr Chairman.

As I am on this Panel, the only commentator from the plant genetic resource side and the only representative of an intergovernmental body, I would like to add some comments on the inter-relation between the important work that lies ahead for your Conference and the already existing work and intergovernmental processes in the field of plant genetic resources (PGR) – in particular, of course, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA).

Having heard the presentations by the authors, my basic observation is that plant and animal genetic resources are very distinct and cannot be forced into the same mould in legal and policy terms. And my basic argument would be that, in their distinctiveness, PGR and animal genetic resources (AnGR) policy *can* and *should* be complementary, mutually supportive and conceived and developed in a coordinated manner.

Conservation, which is addressed under Article 5 of the Treaty, is one of the basic objectives of the ITPGRFA. However, the ITPGRFA comes from the plant side and so what I am about to say has mostly elliptical value as a contribution to this debate.

Introduction to ITPGRFA

As the two areas are so different, let me, for those of you who are not familiar with the Treaty, recall some of the main features of the ITPGRFA. Historically, the work of the Global Plan of Action for Plant Genetic Resources was purely food crop-based. It was during the negotiations for the ITPGRFA that forages were brought in. The Treaty establishes a multilateral system (MLS) for a fixed list of 64 crops and forages, established on the basis of the criteria of food security and interdependence. For these crops and forages the Treaty facilitates access and regulates benefit-sharing.

Farmers' Rights

As the paper mentions, there is a preference for *in situ* conservation recognized by the Commission on Genetic Resources for Food and Agriculture (CGRFA), the prime body for policy in agricultural genetic resources. As we heard this morning, that is where the rights of pastoralists and traditional livestock breeders, who are conserving AnGR diversity *in situ*, come in. You might be interested to know that in the context of the negotiations for the ITPGRFA, we had the same discussion on recognizing and incentivizing the enormous contribution of farmers to the *in situ* conservation of PGR. This discussion led to the adoption of Article 9 of the International Treaty, entitled "Farmers' Rights". So there has been a similar debate on the recognition of traditional communities in the conservation of PGR and the work on implementation of Farmers' Rights is still going on. There may be lessons to be learned there.

Linkages between PGR and AnGR

There may be a case to be made for working with ecosystemic approaches that integrate perspectives on PGR and AnGR to make overall production systems more effective. The linkages are, indeed, there in the production systems – AnGR production systems use crops and forages to produce. The coordination between PGR and AnGR policy may play a particularly important role in facilitating sustainable intensification in crop-based livestock production systems and for conservation in pastoralist production systems.

AnGR and PGR are very different: different biology, different production systems, different use and innovation patterns, etc. Thus, while recognizing that they are inter-related, the differences must be recognized. This is well reflected in the current policy and institutional framework of FAO, where – while they are both in included in the Multi-year Programme of Work (MYPOW) – the process for plants is very different, being mostly contained in the framework of the ITPGRFA.

Lessons that can be learned

In light of rapid change and genetic erosion, there may be need for international regulation and cross-border controls to improve cooperation and development in the AnGR field. If you decide to go that way in this Conference, there are lessons which, I think, might be learned from the ITPGRFA and its negotiations. These lessons include the importance of multilateralism in designing appropriate policy and legal frameworks for genetic resources for food and agriculture. This is so important in agricultural genetic resources because of the millennia of open exchange of genetic resources in agriculture, both in both plant and animal kingdoms, which makes a bilateral approach very difficult to implement.

Another important consideration is the need for a Funding Strategy. The paper recommends that "*an initial step*" of a "*conservation strategy to capture the diversity of breeds*" could be for funding institutions to "*require project proposals to identify conservation needs and to supply costed and timebound plans for such needs*". I am pleased to inform you that an *Ad Hoc* Advisory Committee on the Funding Strategy of the Treaty has just identified some key priorities and eligibility for funding under the Funding Strategy of the Treaty. It has identified "*on-farm conservation of PGRFA*" in particular those listed in Annex I of the Treaty as one of the key priorities for funding of development projects. The Funding Strategy of the Treaty foresees all sorts of actors working together, including through other institutions.

Some concrete suggestions:

- The process following up from this Conference and the monitoring of the possible Global Plan of Action for Animal Genetic Resources can draw upon the Treaty process for support along the lines of the linkages outlined above.
  This would mean:
- Coordinating the processes of the Global Plan of Action for Animal Genetic Resources and the process of the ITPGRFA as far as their respective work on forages and pastures go.
- In a possible future revision of Annex I of the Treaty – which is done according to criteria of food security and interdependence – the needs of livestock production systems and their contribution to food security should be taken into account. This should take into account the importance of grasses and forages for livestock production systems and thereby for food security. This should apply especially to low- and medium-input livestock production systems.

- One target for the priorities under the Funding Strategy could be fodders and feeds – grasses (Africa) and legumes (South America).

Summary of plenary discussion

The meeting was then opened for general discussion and interventions from the floor. Key issues raised during this discussion included:

- The need to identify forces that drive breeds to extinction.
- The need for guidelines to ensure that inappropriate restocking measures are avoided in the aftermath of catastrophes.
- The need to consider policy and legal frameworks for conservation programmes.
- The need to identify priorities for immediate action in the field of conservation.

Responses and final comments of the authors included the following points:

- In general, action is most urgently required where the livestock sector is undergoing rapid changes.
- *In situ* and *ex situ* conservation measures are complementary, but need to be coordinated to ensure that they achieve their objectives effectively.
- Cooperation with conservation organizations interested in specific animal genetic resources is required.