Section F

Methods for conservation

1 Introduction

Breed development is a dynamic process of genetic change driven by environmental conditions and selection by humans, the latter being shaped by the culture and the economic situation. The fact that ecosystems are dynamic and complex and that human preferences change, has resulted in the evolution of breeds and, until recently, a net increase in diversity over time. However, in the past 100 years there has been a net loss of diversity resulting from an increase in the rate of extinction of breeds and varieties. In Europe and the Caucasus alone, 481 mammalian and 39 avian breeds have already become extinct, and another 624 mammalian and 481 avian breeds are at risk. Losses have been accelerated by rapid intensification of livestock production, a failure to evaluate local breeds, and inappropriate breed replacement or cross-breeding facilitated by the availability of high-performing breeds and reproductive biotechnologies (Box 95).

Box 94
Glossary: conservation

For the purpose of this report, the following definitions are used:

Conservation of animal genetic resources: refers to all human activities including strategies, plans, policies and actions undertaken to ensure that the diversity of animal genetic resources being maintained to contribute to food and agricultural production and productivity, or to maintain other values of these resources (ecological, cultural) now and in the future.

***In situ* conservation:** refers to conservation of livestock through continued use by livestock keepers in the production system in which the livestock evolved or are now normally found and bred.

***Ex situ in vivo* conservation:** refers to conservation through maintenance of live animal populations not kept under normal management conditions (e.g. zoological parks and in some cases governmental farms) and/or outside of the area in which they evolved or are now normally found.

There is often no clear boundary between *in situ* and *ex situ in vivo* conservation and care must be taken to describe the conservation objectives and the nature of the conservation in each case.

***Ex situ in vitro* conservation:** refers to conservation external to the living animal in an artificial environment, under cryogenic conditions including, *inter alia*, the cryoconservation of embryos, semen, oocytes, somatic cells or tissues having the potential to reconstitute live animals (including animals for gene introgression and synthetic breeds) at a later date.

Box 95
Red Maasai sheep – accelerating threats

The Red Maasai, renowned for its hardiness and disease resistance, especially its resistance to gastrointestinal parasites, is predominantly kept by Maasai pastoralists, as well as by the neighbouring tribes in the semi-arid regions of Kenya and the United Republic of Tanzania. A number of research projects have demonstrated the breed's resistance to diseases, and high productivity under extremely challenging environments, where other breeds, such as the introduced Dorper perform very poorly. Until the mid-1970s, pure-bred Red Maasai were ubiquitous throughout the pastoral lands of Kenya, probably numbering several million head. In the mid-1970s, a subsidized dissemination programme for Dorper rams was established in Kenya. Widespread indiscriminate cross-breeding followed. No instruction was provided to farmers about how to maintain a continuous cross-breeding programme and many farmers continued crossing their flocks to Dorpers, which subsequently proved unsuitable in many production areas. In 1992, and again more recently, the International Livestock Research Institute undertook an extensive search in Kenya and northern parts of the United Republic of Tanzania, but was only able to locate a very small number of pure-bred animals. The Institute was able to establish a small "pure-bred" flock, but this flock later showed some levels of genetic contamination. The Red Maasai breed is clearly threatened, but the livestock databases DAD-IS and DAGRIS do not identify the breed as threatened, and the breed does not appear in the World Watch List (FAO/UNEP 2000). This is related to the current inability of the systems to document the dilution of breeds.

Provided by John Gibson.

While the loss of livestock genetic diversity has greatly increased in recent decades, the extent of the problem has still not been fully evaluated. Information on AnGR provided by FAO member countries is made available to the public in the DAD-IS database. Although a specific call for information on extinct breeds was made in 1999 before compiling the third edition of the World Watch List (FAO/UNEP, 2000), the lists of extinct breeds are probably not complete – uncharacterized local populations in rapidly developing regions of the world may have disappeared without being recorded. Reasons for extinction are either not documented or not readily accessible, and therefore have not been thoroughly analysed. The risk status of many breeds can only be estimated, as breed population census data are often missing or unreliable. The lack of knowledge hinders concerted actions and the setting of conservation priorities.

2 Arguments for conservation

The ratification of the CBD by 188 states indicates a growing international commitment to sustain and protect biodiversity. The CBD calls for conservation and sustainable use of all components of biological diversity including those used for agriculture and forestry. Recognizing the importance of genetic level diversity it provides a mandate to conserve genetic resources for food and agriculture. Article 2 specifically recognizes "domesticated and cultivated species" as an important component of global biological diversity.

However, it has been noted that

> *"while a significant international consensus regarding policy has apparently emerged, this consensus is not grounded in a consensually accepted value theory to explain why biodiversity protection, however strongly supported, should be a top priority of environmental policy"* (Norton, 2000 in FAO, 2003, p. 105).

For example, the argument for maintaining biological diversity for its own sake can be contrasted with the view that in the absence of a clear case for the utility of a breed, its loss should not be of much concern. This chapter presents an overview of the different lines of argument put forward in favour of conservation. The rationale of a conservation programme may include a combination of the following arguments:

2.1 Arguments related to the past

Livestock breeds reflect the cultural and historical identity of the communities that developed them, and have been an integral part of the livelihood and traditions of many societies. Loss of typical breeds, therefore, means a loss of cultural identity for the communities concerned, and the loss of part of the heritage of humanity.

A further argument relates to the fact that breed development, especially in species with longer generation intervals, will often have involved considerable investments in terms of time, financial expenditure and/or institutional resources. Moreover, historical processes may have given rise to unique outputs that could not easily be recreated. According to this point of view, the decision to abandon such breeds should, therefore, not be taken lightly. There is also a historical dimension to the development of adaptive traits – the longer an animal population has been exposed to an environmental challenge, the greater the possibility that specific adaptive traits have evolved. Areas with climatic extremes or particular disease conditions have given rise to genetically adapted and unique local stocks. These breeds have co-evolved with a particular environment and farming system, and represent an accumulation of both genetic stock, and associated husbandry practices and local knowledge.

2.2 Safeguarding for future needs

> *"Predicting the future is a risky business at best, particularly where human activities are involved"* (Clark, 1995 in Tisdell, 2003, p. 369).

It is notoriously difficult to predict the future, and people's expectations are highly diverse. Very negative expectations may at times be more related to unsubstantiated fears than to rational arguments. However, a strong case for concern about the loss of AnGR diversity can be put forward:

> *"From a long-term point of view, it is possible that concentration on high yielding environmentally sensitive breeds will create a serious problem for the sustainability of livestock production ... it is possible that farmers will lose their ability to manipulate natural environmental conditions. If all environmentally tolerant breeds are lost in the interim, the level of livestock production could collapse."* (Tisdell, 2003, p. 373).

Unforeseen developments may be brought about by changes in the ecosystem, in market demands and associated regulations, by changes in the availability of external inputs, by emerging disease challenges, or by a combination of these factors. Global climate change and the evolution of resistance in pathogens and parasites to chemical control are almost certain to affect future livestock production systems, though the nature of the changes remains unclear (FAO, 1992). The possibility of catastrophic losses of AnGR resulting from major disease epidemics, war, bioterrorism or civil unrest, indicates a need to have a secure reserve, such as a genebank, for breeds that are of great economic importance at present. The uncertainty of future needs, in combination with the irreversible nature of events such as species or breed extinction, highlights the need to safeguard the option value[17] of diversity.

Examples of previously unforeseen needs include the trend among developed-world animal breeders away from production-oriented genetic improvement to focus more on adaptation, disease resistance and feed efficiency. In some developed countries, the importance of conservation grazing has reached an extent that few would have foreseen forty years ago when rare breeds began to be used for this purpose. In the United

[17] The option value of diversity is the value given to safeguarding an asset for the option of using it at a future date.

Box 96
Lleyn sheep of Wales – revival in fortunes in tune with modern demands

In the course of the last half century the Lleyn sheep breed of northwest Wales has progressed from the brink of extinction to a breed of widespread national importance in the British sheep industry. Following the Second World War, the breed retreated from the considerable local importance that it had in the first half of the century, and by the 1960s there were a mere seven pure-bred flocks and 500 ewes. In contrast, by 2006 the number of pure breeders exceeds 1 000 spread throughout the United Kingdom, and regional Society sales involve the annual trading of many thousands of Lleyn sheep.

This revival was achieved through the determination and enthusiasm of an initially small group of twelve local breeders and supportive advisers. They set up a breed society in 1970 to coordinate breeding policy, register pure-bred flocks and grade up cross-bred sheep (by repeated backcrossing using Lleyn rams). The chief attributes of the breed from the start were its medium size, mothering ability (in its hey-day it was milked after weaning the lamb) and prolificacy, as well as meat and wool quality. An added attraction for flock biosecurity was the suitability of the Lleyn for "closed flock" operations in which the only animals purchased are top-quality rams.

These attributes were intensified by organized breeding, partly through the operation of a New Zealand-type nucleus group breeding scheme, involving objective recording (Meat and Livestock Commission) and fast generation turnover. The resulting wide appeal of easily handled ewes, convenient for large and small flock owners, coupled with efficient utilization of expensive land, was fostered by the support of the Breed Society. This involved shrewd marketing, with well-organized breed sales and information provision for prospective buyers and member breeders.

Another important element, as the breed rapidly extended its geographical coverage, was the encouragement given to local devolution. Groups or clubs have been formed on a countrywide basis, currently seven clubs in all, although the parent breed society has maintained its coordinating role and its link with the home base in northwest Wales.

Provided by J B Owen.
For further information on the breed see: http://www.lleynsheep.com

Photo credit: David Cragg

Kingdom, over 600 conservation sites are grazed (although not all with rare or traditional breeds) and as many as 1 000 sites would benefit from such grazing (Small, 2004). Specific breeds which were once under threat but have now proved to be of economic importance include the Piétrain pig. This very lean breed, which is now used in a large number of commercial cross-breeding programmes, was hardly known outside the Brabant province of Belgium prior to 1950. It almost became extinct during the Second World War when fat animals were in demand (Vergotte de Lantsheere *et al.*, 1974). Another example is the Lleyn sheep breed from Wales, which during the 1960s was in serious decline and had a population size of only 500 pure-bred ewes (Box 96). The breed has become increasingly popular among sheep farmers in the United Kingdom in recent years and its population has grown to over 230 000. The Wiltshire Horn, another British breed that was once in decline, is also attracting interest because of changing market conditions. The breed sheds its wool – a desirable characteristic when shearing costs can exceed the price obtained for the fleece.

Opportunities provided by future developments in biotechnology also need to be considered. Emerging reproductive and genetic technologies already provide greatly increased opportunities to identify and utilize the genetic variation of AnGR, and such technologies are expected to show major advances in future. If diverse AnGR remain available, such technologies should make it possible for developing countries to close the productivity gap with developed countries by selectively combining the best features of different breeds.

It is widely accepted that the future option value of AnGR provides a strong reason for conserving AnGR. It is reasonable to assume that changing circumstances and rapidly advancing technologies will require the use of conserved AnGR in the future.

2.3 Arguments related to the present situation

The importance of maintaining threatened AnGR does not necessarily relate only to their potential future use under changed circumstances. There are a number of reasons why the use of these resources may be sub-optimal at present. These reasons fall into three main categories: deficits in information, market failures and policy distortions (Mendelsohn, 2003). There are large gaps in knowledge regarding the characteristics of local breeds and their traits or genes that may be important for production, research purposes or to meet other human needs (Oldenbroek, 1999). Imperfect information may lead to the overestimation of the performance of a breed within a particular production environment where its introduction is being considered, and hence an inappropriate decision regarding its adoption. It is, of course, also possible that imperfect information could lead to farmers unnecessarily retaining their indigenous breed and not adopting alternative breeds that would improve their livelihoods.

Policy distortions can put less intensive production systems at a disadvantage and provide disincentives for efficient resource allocation. A narrow focus on high-output breeds may be favoured by policies such as subsidized grain imports, free or subsidized support services (e.g. AI) or support prices for livestock products, which stimulate the intensification processes. For example, in some rapidly industrializing Asian countries important capital subsidies have clearly favoured an industrial mode of development; cheap capital has led to investments in large commercial units associated with high input use and uniform products. Furthermore, development or emergency programmes sometimes promote exotic breeds from donor countries. Finally, political instability and policies unfavourable to vulnerable livestock keeping populations may inhibit the efficient use of AnGR (Tisdell, 2003).

Markets may not accurately represent external costs or benefits. Examples of external costs include negative environmental impacts, and undesirable effects on income distribution and equity. External benefits associated with certain breeds may, for example, include their contribution to landscape management. Mendelsohn (2003, p. 10) suggests that:

> *"Conservationists must focus on what the market will not do. They must identify and quantify the potential social benefits of AnGR that have been abandoned by the market."*

The preservation of diversity, including within-breed diversity, serves to maintain stability in production systems. Diverse populations show greater ability to survive, produce and reproduce under conditions of fluctuating feed resources and water supply; extremes of temperature, humidity and other climatic factors; and low levels of management (FAO, 1992). There is evidence that they are also less susceptible to catastrophic epidemics (Springbett *et al.*, 2003). In general, genetically uniform populations are less able to respond to strong selection pressures resulting from environmental changes. Maintaining breed diversity enables people to exploit diverse ecological or economic niches. This is particularly the case in marginal and environmentally fragile areas, such as drylands, where most livestock kept by poor farmers are located, and which are characterized by great diversity and high levels of risk.

Arguments for existence and bequest values for AnGR,[18] remove the need to identify tangible or non-tangible benefits as a justification for conservation.

> *"Biological diversity has intrinsic value and should be conserved for its own sake to the maximum extent possible, regardless of whether any given component can be shown to produce tangible economic benefits"* (FAO, 2003, p. 104).

However, the development of breeds within domesticated species is primarily the product of human intervention to meet human objectives and values. The argument that the current diversity should be preserved on the grounds of its existence value is, therefore, perhaps more difficult to defend than in the case of the biodiversity of natural ecosystems.

Arguments and capacities for conservation vary from region to region. In Western societies, traditions and cultural values are important driving forces, which ensure the development of conservation measures for rare breeds and promote the emergence of niche markets for livestock products. By contrast, in the developing world, the immediate concerns are for food security and economic development. However, most developing countries are already in a process of economic evolution, and their economies can be expected to become sufficiently developed to support conservation based on cultural heritage and other such drivers at some point in the future. There is a need to ensure that AnGR are not lost before this self-supporting stage is reached.

3 The unit of conservation

A critical first step in the design of AnGR conservation programmes is to decide what is to be conserved. At the molecular genetic level, the genetic diversity present within a livestock species is a reflection of allelic diversity (i.e. differences in DNA sequences) across the 25 000 or so genes (i.e. functional DNA regions) affecting animal development and performance. Conceptually, therefore, the most basic unit of conservation is the allele. An objective might be to design conservation programmes that will both allow maintenance of a preponderance of the alleles that are currently present within a species, as well as providing for the normal accumulation and potential retention of the newly arising mutant alleles which are the fuel for continued animal evolution and improvement. Allelic diversity could, in theory, be quantified by enumeration of the number and frequencies of the various alleles, but for the moment this is an impossible task. In defining the unit of conservation, it must further be recognized that alleles do not act in isolation, and that animal performance in most cases is properly viewed as a result of the interactions of alleles present across the genome. Thus, the process of genetic resource development involves the creation of allelic combinations that support specific desired levels of animal performance and adaptation. Efficient genetic resource conservation, therefore, involves the creation of structures that allow for maintenance of existing genetic combinations of known adaptive or productive value, and for easy access to these combinations to support future animal production needs.

[18] The existence value is derived from the satisfaction of knowing that a particular asset exists; a bequest value is the benefit accruing to any individual from the knowledge that others might benefit from the resource in the future.

Existing livestock breeds are less genetically uniform than most varieties of crop plants, but nonetheless represent the realization of a diverse set of adaptive processes. The population structure of the major livestock species up to the mid-twentieth century conformed closely to the population structure predicted to maximize evolutionary potential. There were many partially isolated subpopulations (the breeds), maintained under diverse conditions, but with periodic exchange of animals among populations and periodic recombination of breeds to yield new genetic combinations. Thus, adoption of the breed as the unit of conservation is expected to maximize the maintenance of evolutionary potential within livestock species, and likewise to maximize access to a broad array of allelic combinations.

4 Conservation of plant versus animal genetic resources

Organization and implementation of the SoW-AnGR assessment process was based on the lessons learnt from the global assessment of plant genetic resources (PGR) and the resulting Report on the State of the World's Plant Genetic Resources (FAO, 1998a). Accordingly, the SoW-AnGR process focused on both the preparation of the first Report, and the initiation of actions at national level arising from the process of Country Report preparation. Nevertheless, approaches for conservation of PGR cannot be directly applied to AnGR.

In traditional production systems, plant and animal genetic resources are used in comparable ways. Locally adapted breeds and varieties predominate; seed for planting, and breeding animals are drawn from the farmers' fields, herds and flocks, and genetic diversity within resulting landraces is substantial. Most breeding and development activities are "participatory" (FAO, 1998a) in the sense that decisions regarding the seeds to save for planting and the animals to retain for breeding are made by farmers rather than professional plant and animal breeders. However, intensification of agriculture has resulted in important changes in patterns of genetic resource utilization and development. In plants, intensification of crop production has generally been accompanied by emergence of a strongly institutionalized and centralized seed production sector dominated by publicly funded national and international centres, and private firms. In contrast, the intensification of the livestock sector is currently much less advanced, and has been a result of, rather than a prerequisite for, economic development. The animal breeding sector is far less centralized and institutionalized than the plant seed sector, although there has been substantial movement towards centralization in the poultry, pig and, to a more limited extent, dairy cattle sectors. Direct involvement of farmers in animal breeding remains substantial for the other livestock sectors, and AnGR utilization and further development remains strongly "participatory" in certain production environments. The different structures of the seed and seedstock sectors in plants and animals have important implications for the conservation of global genetic resources.

Table 104 compares a number of biological, operational, and institutional factors that influence conservation activities in plants and animals. Biological differences clearly require different approaches to conservation, but perhaps the most significant difference between the crop and livestock sectors involves institutional capacity for genetic resource management. Many of the institutions of the seed sector already maintain extensive collections of PGR, and actively contribute to the development and release of plant varieties. The databases of the World Information and Early Warning System on Plant Genetic Resources (WIEWS) record the location of over 5.5 million PGR accessions, in some 1 410 *ex situ* collections around the world (FAO, 2004).

Establishing a genebank for animals involves long-term storage of gametes, embryos or somatic cells in liquid nitrogen. Technical aspects of such *in vitro* conservation in animals are discussed in detail below, but costs to collect, cryoconserve and subsequently reconstitute animal germplasm are many times greater per preserved genome than costs to collect, store and subsequently utilize seeds. Moreover, funding to support the conservation of animal germplasm has been insufficient. As a result, AnGR conservation has much more heavily emphasized *in situ* approaches. However, with the exception of a small number of developed countries, there has been little action to establish *in situ* conservation programmes, and the long-term sustainability of such schemes remains uncertain.

DAD-IS lists 4 956 extant mammalian breeds and 1 970 extant avian breeds. Few of these are well represented in *in vitro* collections and almost none have been sampled at levels consistent with FAO (1998b) guidelines for *in vitro* sampling. Very substantial resources would be required to develop *in vitro* collections of even the most endangered of these nearly 7 000 livestock breeds. For example, the FAO (1998b) Guidelines for Management of Small Populations at Risk recommend collection of frozen semen from at least 25 males per breed, and use of semen from these males on an additional 25 females per breed to produce frozen embryos. For cattle, with 300 endangered breeds, cryoconservation of semen from 7 500 males and approximately 100 000 embryos would be required. Policy guidelines for ownership, use and management of *in vitro* collections are yet to be developed.

Institutional capacity for AnGR conservation is limited, with only a few national *ex situ* collections existing, mainly in developed countries. Among the institutions of the Consultative Group on International Agricultural Research (CGIAR), only the International Livestock Research Institute (ILRI) and the International Center for Agricultural Research in the Dry Areas (ICARDA) actively address issues of better management of AnGR, and neither institution has an active programme for long-term storage of germplasm. Ownership of AnGR resides almost exclusively in the private sector. A substantial enhancement of global capacity for conservation and better use of AnGR, with new institutional models and collaboration among public institutions and between public institutions and private farmers, may therefore be required if the recommendations of the SoW-AnGR process are to be implemented.

5 Information for conservation decisions

Setting priorities for AnGR conservation requires a process that enables the identification of breeds that contribute most to global genetic diversity and have the greatest potential to contribute to efficient future utilization and further development of that diversity. Additional criteria, such as cultural or heritage values of a breed, will also affect priorities for conservation.

Assessing the likely genetic diversity present in a set of breeds may be based on a variety of criteria, including:

- trait diversity, which is diversity in the recognizable combinations of phenotypic characteristics that define breed identity;
- molecular genetic diversity, based on objective measurements of genetic relationships among breeds at the DNA level; and
- evidence for past genetic isolation as a result of either geographical isolation or of breeding policies and cultural preferences applied in the communities where the breeds were developed.

Trait diversity is based on heritable phenotypic differences among breeds. When breeds are compared under comparable environmental conditions, trait diversity is necessarily indicative of underlying functional genetic diversity. For this reason, breeds that possess unique or distinctive trait combinations should be given high priority for conservation, because their unique phenotypic characteristics necessarily reflect unique underlying genetic combinations.

TABLE 104
Comparisons of biological, operational and institutional factors influencing plant and animal genetic resources conservation

Factor	Plants	Animals
Economic value of production per individual	Low to very low	Moderate to high
Reproductive rate (number of progeny per individual per generation)	High to very high (1000s)	Very low (<10) to moderate (<200) except for males of species (mainly cattle) where widespread use of artificial insemination is feasible (10 000s)
Generation interval	0.25 to 1 year	1 to 8 years
Within-line genetic diversity	Very limited in most plant varieties	Very substantial in most livestock breeds
Cost to record performance of an individual or family	Very low to low	High to very high
Cost to assess adaptation or disease resistance for an individual or family	Very low to moderate	Very high
Ability to conserve diversity of wild relatives under natural conditions	Common for plants	Rare in animal species
Ability to self-fertilize and develop inbred lines	Possible and routine in many species	Self-fertilization is not possible; due to depression, high levels of inbreeding have to be avoided; in specific cases inbred lines are used for crossing
Clonal propagation	Possible and routine for many species	Technically feasible but too inefficient even for most research purposes
Ability to collect germplasm	Simple in most cases	Technically feasible but requires facilities and trained personal
Ability to store germplasm *in vitro*	Seed storage in cool conditions is feasible for most species; a few species require tissue culture; in some cases cultures can be stored in liquid nitrogen	Feasible for male gametes of most species and female gametes of some species; storage of embryos is feasible for most mammalian species, but at much greater cost compared to spermatozoa; material from all species must be stored in liquid nitrogen
Requirements for regeneration of stored material	Most require periodic restoration to replenish stored material and maintain viability	Essentially permanent storage
Cost of extracting, regenerating, and testing material from a genebank	Relatively easy and with relatively low cost; tens of thousands of accessions are extracted and tested annually	Both regeneration and testing are difficult and time consuming; there has been little experience with the extraction and use of stored material
Status and scope of genebanks	Extensive collections at several locations globally include millions of accessions for hundreds of species mainly involving seed storage with relatively low collection and storage costs	Restricted to a small number of developed countries, mainly involving frozen semen
Ongoing collection of wild and indigenous germplasm	Lower levels than in past years, but still a significant effort, especially for neglected species	Very little activity, especially in the developing world
Institutional support for conservation	Substantial, well-organized, and stable	Limited, often poorly organized, some exception in developed countries

In the table, “plants” refers specifically to the annual plants that dominate food and agricultural production, but it is recognized that long-lived perennial plants such as trees have significant elements in common with animals. Similarly, “animals” include both relatively fecund species such as chickens, which have some elements in common with plants (e.g. the potential for annual replacement of commercial flocks), and very extensively managed, long-lived species such as the dromedary.

Trait diversity expressed at the level of complex quantitative traits such as disease resistance, milk production or growth rate is generally given higher priority in conservation decisions than trait diversity associated with simply inherited traits such as coat or plumage colour, horn shape or body type. These simply inherited traits can be changed rapidly in response to owner preferences, whereas differences in complex quantitative traits generally involve larger numbers of genes, take longer to change, and therefore have greater potential to reflect underlying genetic diversity.

Box 97
Decision-making in conservation and utilization – use of genetic diversity data

It is only recently that the value of genetic diversity data in conservation and utilization of AnGR has been recognized and applied. The Global Environment Facility (GEF) is supporting a project on conservation of trypanotolerant cattle, sheep and goats in four West African countries, which started in 2005. In much of the region, the purity of trypanotolerant breeds has been diluted by past cross-breeding with non-trypanotolerant breeds. However, this lack of purity is not immediately obvious in the appearance of the animals. Molecular genetic markers are being used to map the diversity of these breeds and identify the most pure populations, which will then be the focus of conservation and further development. Meanwhile, an ongoing International Atomic Energy Agency (IAEA) programme is mapping molecular genetic diversity among Asian sheep and goat breeds. The genetic diversity data will then be combined with phenotype data to identify breeds in which different mechanisms of resistance to the same disease have evolved. These breeds will then be crossed, and molecular genetic markers used to map the genes controlling resistance in order to confirm that different breeds have evolved different mechanisms of resistance. If this is confirmed, these different mechanisms can be used in further genetic improvement programmes.

Provided by John Gibson.

Direct measures of molecular genetic relationships among breeds are increasingly becoming available and also provide an indication of genetic diversity. These measurements are based on variation in DNA sequences, usually in neutral regions of the DNA that are not thought to influence animal performance or phenotype. For this reason, molecular measures of genetic diversity reflect differences in evolutionary history, but provide only indirect indications of genetic diversity in functional or potentially functional regions of the DNA. Breeds that appear closely related based on allelic frequencies at neutral loci may nonetheless differ importantly at functional loci as a result of divergent selection histories. For example, genetic distance information, derived using few randomly selected genetic markers does not provide information on specific genetic variations such as the double-muscling allele in Belgian Blue cattle, or the dwarf gene in the Dexter (Williams, 2004). For this reason, trait diversity generally warrants first consideration in choosing candidates for conservation. However, phenotypically similar breeds may evolve as a result of different genetic mechanisms, and measures of molecular genetic diversity can aid the identification of breeds that are superficially similar but genetically distinct. Conservation of genetically unique breeds is, likewise, justified because these breeds are more likely to exhibit functional genetic diversity for traits previously unmeasured or unexpressed, but that may be of future importance in new markets, with exposure to new diseases, or under different production conditions.

Measures of molecular genetic diversity are attractive as a basis for conservation decisions because they yield quantitative measures of relatedness which can, in turn, be used to assess genetic diversity within a set of breeds. In contrast, trait diversity is more difficult to quantify objectively, especially for quantitative traits and for small groups of breeds. Past efforts to quantify phenotypic differences have focused mainly on morphological measures at species or

Box 98
Spatial analysis of genetic diversity

The mapping of molecular genetic information in a Geographic Information System (GIS) allows spatial analysis of the genetic information. GIS can be used to study spatial structures, distribution and distance of genetic data; to simulate animal population migrations in the landscape; to visualize and analyse geographic population structures; to define diversity zones; to detect areas of genetic differentiation; and to examine the interaction between environment and genetic variants.

The Econogene project (http://lasig.epfl.ch/projets/econogene/) was designed to combine molecular genetics with spatial analysis to document the spatial distribution and environmental correlates of genetic diversity among small ruminants in Europe. DNA was sampled from over 3 000 animals spread from Portugal to eastern Turkey. A set of 30 microsatellites, 100 AFLPs and 30 SNPs were assayed in these animals and more than 100 environmental variables were recorded. Geovisualization (GVIS) tools were then used to observe the patterns of physical association between various components of genetic variation and spatially varying environmental factors. Such visualizations led to the development of hypotheses for causative associations between environmental and anthropic factors and genetic variation. For example, the association of alleles of several molecular markers with selected environmental variables was tested. The testing included a set of AFLP molecular markers, which were not related to any specific trait, and a variety of environmental variables (mean temperature, diurnal temperature range, relative humidity, sunshine, ground frost frequency, wet day frequency, wind speed and precipitation). Three AFLP markers were found to be significantly associated with one or more variables, probably pointing to adaptation to a humid environment (e.g. coefficient of variation of precipitation, number of wet days, relative humidity, sunshine and mean diurnal temperature range).

The results were compared with those obtained with the application of a completely independent population genetics method. Two genetic markers were indicated to be under selection by both approaches, validating 31 percent of the significant associations identified by the spatial analysis. These results are particularly encouraging as they seem to validate an approach which is independent of any population genetics model (see Joost (2005) for further details).

Provided by Paolo Ajmone Marsan and the ECONOGENE Consortium.

subspecies levels in natural populations. In the absence of widespread access to molecular genetic information, results had value as indicators of evolutionary distance, but are less useful in domestic animals where artificial selection can lead to rapid morphological changes, such as those observed in domestic dogs or fancy poultry. Objective assessment of genetic diversity at functional or potentially functional sites will, thus, require further development of objective methods to combine information on trait and molecular genetic diversity (see Section F: 8).

Historical information or evidence of long-term genetic isolation can be used in the absence of information on trait or molecular genetic diversity, but can also be misleading. Population genetics theory shows that very low levels of movement of animals between seemingly isolated populations can effectively prevent meaningful genetic differentiation. Thus, breeds with a history of genetic isolation are important candidates for careful trait and molecular genetic characterization, but final decisions on genetic uniqueness are better made using more objective tools. It should be recognized, however, that livestock breeds developed as a result of cultural preferences in isolated rural communities may be an important part of community identity and heritage. Conservation of such breeds may merit consideration as part of broader community development efforts, regardless of their predicted value as a unique global genetic resource.

6 *In vivo* conservation

The term "*in vivo* conservation" describes conservation of live animals and encompasses *in situ* and *ex situ in vivo* conservation methods.

6.1 Background

Conservation of AnGR takes place in a wide variety of contexts, varying in terms of species, breed, geographic region, and farming, social and economic systems. Conservation can also have a wide variety of objectives. Emphasis may be placed on the conservation of genetic resources or diversity *per se*; on the environmental services through which livestock contribute to the conservation of the wider ecosystem; on the socio-economic consequences of conservation; or on the cultural significance of maintaining particular livestock breeds. Approaches to the conservation of AnGR can differ significantly in their capacity to achieve the various conservation objectives, and in terms of their applicability in different contexts.

It is possible to view *in vivo* conservation techniques as a spectrum of different approaches: at the *in situ* end of the spectrum is the maintenance of breeds within their original production systems, while the extreme *ex situ in vivo* approach is to keep the breeds in zoos. Ranged between the two extremes are: maintaining the species under farm conditions but outside the environment in which they evolved; the maintenance of limited numbers of animals in special-purpose conservation farms, in experimental or educational herds; and keeping breeds for pasture or landscape management within protected areas. Faced with the diversity of potential conservation measures, it is sometimes difficult to make a clear distinction between *in situ* and *ex situ in vivo* approaches. For instance, governmental stations can be considered as applying *in situ* or *ex situ in vivo* conservation methods depending on location and husbandry practices.

There is no single prescription for a successful conservation programme. Numerous breed conservation activities have been undertaken, particularly since the 1980s. However, almost no attempts have been undertaken to analyse adequately the factors underlying the success or failure of *in vivo* conservation programmes. Such analyses are also constrained by the limited availability of data.

6.2 Genetic management of populations

Detailed discussions of many of the requirements for genetic management of populations can be found in Oldenbroek (1999).

Small populations and genetic variation

Whenever breeds are conserved *in vivo*, whether *in situ* or *ex situ*, they should be managed in ways that maintain their genetic variation in the long term. It is well known that a small population size may lead to loss of allelic diversity and an increase in inbreeding. Maintaining sufficient effective population sizes to preserve genetic variation is a central theme of long-term breed management. Apart from increasing the number of animals in the population, management techniques to maintain genetic diversity include maintaining a narrow sex-ratio. This is because even if the number of females in the population is large, high-intensity selection schemes can reduce the number of breeding males considerably, and result in a small effective population size and consequent high inbreeding increments. Another method is to minimize variance in the numbers of progeny produced by individual breeding animals, which reduces the average relationship among the animals available for breeding in the next generation.

The population should also be large enough to allow natural selection to purge deleterious mutations which could otherwise accumulate in the population as a result of genetic drift. It is significant for the management of small breeding populations that there is a threshold effective population size below which the fitness of the population decreases steadily. Based on the most recent estimates of mutation rates, this threshold of effective population size is considered to be between 50 and 100. The minimum population size required will therefore be above 50.

Another possible management technique is the use of cryoconserved genetic material in *in vivo* conservation schemes in order to increase the effective population size. The combined use of molecular genetic and pedigree information has also been proposed. Such techniques, however, require substantial expertise and expense, and may be too costly for many countries. Most of the theoretical and implementation models that have been developed refer to pedigree populations with a high degree of herd and animal management. Such models are likely only to be relevant for a limited number of species in a limited number of countries. Management schemes that can be implemented in populations with limited genealogical information have been developed (Raoul *et al*., 2004). However, field testing and further methodological development is needed to adapt them to situations with limited organizational capacity and funding.

Selection in local breeds

Breeds are dynamic, undergoing continuous genetic change in response to environmental factors and active selection by livestock keepers. The indigenous breeds of the developing world are rarely subject to modern breeding techniques. However, selection programmes can increase the frequency of genes desirable for the productivity and profitability of local breeds. Such measures will undoubtedly be required if local breeds are to remain a viable livelihood option for the farmers who maintain them. Selection schemes need to take into account the maintenance of genetic variation within the breed and the risks associated with high rates of inbreeding. Traits under selection need to be accurately recorded, and the highest responses to selection result from the use of statistical genetic estimates of breeding value. Controlled breeding, based on estimates of breeding value, result in inbreeding rates two to four times higher than those that result from random selection of parents. However, techniques have been developed to optimize selection so that a suitable balance between inbreeding and genetic improvement can be achieved. Such methods should be of particular advantage in small populations, but there has been little work on how they should best be applied in developing-country situations. As a broad generalization, genetic improvement in local breeds will often involve a greater emphasis on characteristics[19] contributing to low production costs, and the environmental and cultural values of the associated farming systems. Traits proposed for selection will need to be accurately evaluated for their genetic relationships with traits that determine the conservation value of the breed, so that possible negative effects on key adaptation traits are avoided.

6.3 Self-sustaining strategies for local breeds

The sustainability of a given breed is affected by many factors including: cultural, social and food demand changes; transformation of the food production chain; changes to policies and national and international legal frameworks affecting the importation of germplasm and livestock products; economic development; and technological changes. In most cases, it is a combination of changes in production systems

[19] A greater focus on disease resistance, feed efficiency and general adaptation is also being applied to genetic improvement of more commercially oriented breeds, driven by concerns about possible failure of existing disease control measures, legislated reduction or elimination of the use of antibiotics, and concerns about the costs of external inputs, particularly related to the use of fossil fuels.

and lack of current economic profitability that plays the major role in the decline of a breed. The question arises: what options are available to halt and reverse the process of breed decline? Possible options for achieving self-sustainability are described below.

Identification and promotion of quality products

Many local breeds are able to provide unique products that may be of a higher quality than those obtained from high-output commercial breeds. Local breeds and their products may also be valued as a characteristic part of traditional farming systems. Moreover, many local breeds

Box 99
***In situ* conservation of the Norwegian Feral Sheep**

The Norwegian Feral Sheep is a remnant of the sheep populations kept in Norway during the days of the Vikings. In 1995, it was confirmed that the breed was threatened with extinction. There were an estimated 2 000 animals in the country at that time, mostly kept in western Norway.

A few committed individuals, centred on an active and long-established sheep breeding community in Austevoll in the county of Hordaland, decided to try to save the Feral Sheep and develop a niche industry based on the breed. In June 1995, the Norwegian Feral Sheep Association was established. The association is a nationwide, cooperatively managed society with about 300 members. The objectives of the association are to conserve the breed and improve its profitability, by adapting production methods and products to market demands, and by raising public awareness.

The association quickly established a set of production standards which had to be met if products were to be certified under the "Feral Sheep" label. These standards include both a breed description, and certain requirements regarding production methods. An important aspect of the association's producer standards is also to safeguard traditional farming methods, which are a continuation of the way in which Feral Sheep have been kept in Norway for centuries. Requirements specify that the sheep are kept outdoors all year round, and that they have access to a protective shed if there is no natural shelter available. As a rule, the use of feed concentrates is also prohibited. Meat from the Feral Sheep has been welcomed by consumers. The characterful, tasty meat is regarded as a fashionable niche product. Another important aim of the breeding association is to maintain the coastal heathlands and other cultural landscapes. These landscapes, with grazing Feral Sheep, are increasingly popular attractions for tourists.

In 2003, only eight years after the first conservation measures were introduced, the Feral Sheep population exceeded 20 000 animals. Most Feral Sheep are still found in western Norway, but there are initiatives to introduce this special form of sheep farming in the coastal regions of central and northern Norway, as part of the development of rural industries in these areas.

Provided by Erling Fimland.

Photo credit: Erling Fimland

have long played a central role in the social and cultural life of rural populations – including religious and civic traditions, folklore, gastronomy, specialized products and handicrafts (Gandini and Villa, 2003).

These characteristics can potentially be a basis for diversified livestock production, and increased profitability for local breeds. Conservation objectives have been promoted both through direct subsidy (see below), and through the promotion of high-value specialized products. The latter approach has been particularly successful in Mediterranean areas, where the diversity of breeds and production systems is still associated with a variety of animal products, food preferences and cultural traditions. Unfortunately, even in this part of the world, it is probable that the majority of such relationships that were present in the mid-nineteenth century have been lost. The strategy is supported by current European certification systems for agricultural products, such as the PDO (Protected Designation of Origin) and the PGI (Protected Geographical Indication), and also by the development of specific commercial brands.

In case of Europe, these conservation efforts are implemented within a highly developed economy that can support diverse high-value products, and actions to support cultural and environmental goals. Opportunities to apply such approaches are likely to be more limited in less-developed economies; but examples do exist, such as the higher price achieved for meat from native Creole pigs in Yucatan, Mexico, and for native chicken meat in several Asian and African countries. As economies develop, the cultural identity of breeds is likely to become more important as an aspect of marketing and as a policy goal, and hence offer greater opportunities for the achievement of breed self-sustainability.

Ecological services

Breeds adapted to local production conditions are often the best suited to provide environmental services such as landscape management, including the stimulation of desired types of vegetation growth, fire or avalanche control, and keeping power line and wildlife corridors free of brush (thereby reducing herbicide use). There may be opportunities even in less-developed economies to sustain a variety of culturally important breeds through ecological and cultural tourism, or other novel approaches to income generation for livestock keepers. An example might be the use

Box 100
Examples of incentive payment schemes at the national level

In the United Kingdom, the Traditional Breeds Incentive scheme run by English Nature (a government nature conservation agency) covers livestock kept at, or adjacent to, sites of special scientific interest (English Nature, 2004). The premise is that traditional breeds are often better adapted to grazing the herbage found at these sites, and thus do a better job where grazing is required for conservation purposes. Here, the objective is broader than simply preserving the breeds *per se*, and the incentive payments to the farmers can be regarded, in part, as payments for the broader environmental services provided.

In Croatia registered breeders of locally adapted endangered breeds receive state subsidies totalling around US$650 000 *per annum* (CR Croatia, 2003). Fourteen breeds including Istrian cattle, Slavonian-Podolian cattle, Posavina horse, Murinsulaner horse, Turopolje pig, Black Slavonian pig, Istrian sheep, Ruda sheep, Zagorje turkey and some donkey breeds are covered by the scheme. Similarly, in Serbia and Montenegro, the Department for Animal and Plant Genetic Resources of the Ministry of Agriculture operates a payment scheme for supporting the on-farm conservation of locally adapted breeds of horses, cattle, pigs and sheep (Marczin, 2005).

In Myanmar, population numbers of Shwe Ni Gyi cattle were increased through the provision of subsidized semen, and the payment of a small amount (equivalent to US$1) to owners when they registered a pure-bred animal (Steane *et al.*, 2002).

of local cattle to maintain healthy ecosystems that promote increased animal density and diversity in large wildlife parks. The challenge is to translate such breed services into economic rewards for the livestock keepers.

Incentive measures

A lack of profitability relative to other breeds, and hence a lack of popularity with farmers, is frequently a reason for the decline of a breed's population numbers. One potential approach to conservation is to offer farmers financial incentives to compensate them for income that they forgo by keeping the less profitable breed. This approach is only feasible where resources are sufficient and there is political will to expend public funds to meet conservation objectives; where breed characterization is sufficient to allow breed populations to be identified and classified according to their risk status; and where the institutional capacity is in place to allow eligible farmers to be identified, to monitor their activities, and to administer payments. It is perhaps not surprising that incentive schemes for breed conservation have largely been restricted to Europe. Schemes have been in place in the EU since 1992 (for a further discussion of EU legislation covering incentive payments see Part 3 – Section E: 3). Such incentives have halted the decline of some, but not all local breeds. A number of national-level schemes have also been put in place, again mostly in Europe (see Box 100 for examples). Even where successful, the longer-term sustainability of such incentive systems is questionable. It seems worthwhile to investigate the use of more specific incentives; in Europe for example, the elimination of milk production quotas for endangered breeds might promote their wider use. In general, economic incentives should be designed to accelerate the achievement of breed self-sustainability rather than merely to provide temporary economic support.

Box 101
An index of economic development potential for targeting *in situ* conservation investments

The Econogene project combines molecular analysis of biodiversity, with socio-economics and geostatistics in order to address the conservation of sheep and goat genetic resources and rural development in marginal agrosystems across Europe. Samples of genetic material were collected in seventeen countries in Europe and the Near and Middle East. (http://lasig.epfl.ch/projets/econogene/)

One of the objectives was to help make expenditure of funds more effective. The project developed an index of development potential, provided as a simple tool that can be used to determine where public money can best be spent to maximize response. Application is possible at different levels: from a single farm up to a region. The index is a weighted sum of three sub-indexes that evaluate, (1) the economic characteristics of the firm/farm (single or average from a region), (2) the social characteristics of the firm/farm, (3) marketing strategies. Each sub-index is based on a variety of inputs. In the case of the Econogene study of EU sheep and goat breeds, the relative weights in the economic development index were 50 percent for the economic dimension, 30 percent for the social dimension, and the remaining 20 percent for marketing strategies. The index does not include environmental factors, such as climatic conditions, availability of agricultural land or pasture, or public administration factors. These factors can affect outcomes when the policy tools are applied, but the index evaluates only the economic potential resulting from the characteristics and behaviour of the private sector.

Provided by Paolo Ajmone Marsan and the ECONOGENE Consortium.

Box 102
Community-based *in situ* conservation programme – a case from Patagonia

Neuquén criollo goats are the main source of income and animal protein for many households in the north of Neuquén province in Argentine Patagonia. The goats are well adapted to the transhumant movements which have traditionally shaped the lives of the goat keepers or *crianceros*. The sustainability of the system is, however, threatened by changes restricting livestock movements, notably the fencing of traditional grazing areas. Prospects of education, employment and better housing offered by more urbanized lives also promote sedenterization. Attempts during the 1980s to introduce Angora and Anglo-Nubian goats for fibre and milk production proved unsuccessful because of the harsh environment. Nonetheless, indiscriminate cross-breeding poses a threat to the local genetic resources. A programme for the conservation and improvement of the Neuquén criollo goat was established in 2001 under the auspices of the Instituto Nacional de Tecnología Agropecuaria (INTA) and the provincial Agricultural Bureau. Organizational and technological innovations which promote the continuance of the traditional system under changed circumstances have been introduced. The goat keepers have been involved in the programme since its inception through the establishment of producers' associations which play a leading role in the development and diffusion of new technologies.

Genetic improvement work is oriented towards conserving the breed's genetic variability, hardiness and productive efficiency within the framework of the traditional system. The programme is developing a system for providing improved strains of local ecotypes based on selection criteria proposed by the *crianceros* themselves. Preferences are for large but compact animals that provide good meat yield and can withstand extreme environments. The *crianceros* also pay attention to does' suitability for breeding and kidding. A preference for white goats is related to the marketing of the hair. Conversely, goats with

Photo credit: María Rosa Lanari

coloured coats are considered easier to manage in snow-covered pastures. This preference is strongest in areas where snow lies longest. Further developments include measures to increase the value of goat products. Kid meat is now sold under a distinct "geographical indication". This commercial–legal innovation enhances the profitability of the traditional product of the system. A newer undertaking for the goat keepers is the harvesting of cashmere. Recent studies of the fibre from the breed have revealed the potential of this product. The *crianceros* have been provided with combs and trained to harvest and classify the fibre.

The aim is, thus, to forestall the breed's genetic dilution as part of integrated efforts to preserve the underlying production system. The goat breed, the local environment, the culture and traditional practices of the *crianceros* are regarded as valuable assets that can be used to enhance the development of this rural area.

Provided by María Rosa Lanari.
For further information see: FAO (2007a).

Utilization in production systems

Higher productivity resulting from genetic improvement of local breeds can imply higher intensity of management and the need for supporting infrastructure. Conversely, improvement in production systems and infrastructure can stimulate improvement of the local breed and/or the importation of new breeds. Such development can be both an opportunity and threat to the maintenance of local breeds. For example, indiscriminate cross-breeding can be a major threat. However, if properly structured, cross-breeding can lead to maintenance of the local breed, for example, as a highly adapted and efficient dam breed in a recurrent cross-breeding programme. Unfortunately, little is known about how to improve production systems and infrastructure such that the livelihoods of local people are improved and food security is achieved while also conserving indigenous AnGR.

6.4 *In situ* versus *ex situ* approaches to *in vivo* conservation

Given the intimate and complex relationships between indigenous communities, environments and livestock, and a widespread lack of breeding services and infrastructure, community-based management of AnGR is often seen as a solution (Köhler-Rollefson, 2004), and is widely promoted by NGOs. Certainly, such community-based approaches to conservation seem the preferable option if they support further development of the breed and its ability to enhance livelihoods. Many of the conservation strategies based on high-value products or production services, discussed above, have been built around community-based, *in situ* conservation. It has to be ensured that maintaining local breeds will enhance the short and long-term livelihoods of the communities that keep them. If this is not the case, such strategies will prove unsustainable as the communities will eventually switch to alternative breeds that provide better livelihoods.

Community-based management approaches do exist in the developing world. The example described in Box 102 illustrates that even where

Box 103

Changes in production systems leading to replacement of local buffaloes – a case from Nepal

Parcelling out of available grazing land as a result of population growth has had a large impact on traditional livestock farming systems in the Mid-Hills of Nepal. Rural households with access to growing urban markets have replaced low-yielding local cattle and buffaloes with high-yielding dairy buffaloes that can be stall-fed. In less than 30 years, more than 95 percent of farm households in the area covered by this case study have replaced their local cattle and Lime buffaloes with one to three high-yielding Murah milk buffaloes from the Indian lowlands. About 65 percent of households buy new animals in lactation each year, selling the dry ones for rebreeding or meat. The imported buffaloes are bred in the Indian lowlands, and selected by Indian traders, who transport them to the highlands of Nepal and purchase the dry animals. These private traders have played a much more important part than the government in promoting the utilization of higher-yielding animals. The local buffalo and cattle breeds will remain important in more remote rural areas where they continue to provide draft power and give enough milk for family subsistence.

Initial obstacles to managing the newly introduced breed have been overcome, and farmers no longer wish to return to using the local animals. Farmers have kept improved buffaloes successfully on a prolonged basis, and have been rewarded with an improved standard of living. Their priority now is to further develop breeding strategies for the Murah buffaloes to achieve even better productivity. This requires collaboration between the breeders of Nepal and India.

Socio-economic changes led farmers to abandon traditional farming practices and to seek alternatives. The new management strategies have provided higher economic returns, and farmers have come to favour an introduced breed over their local animals. This case study shows that as production conditions change, new breeds with different characteristics sometimes provide farmers with a better livelihood option than local breeds.

Provided by Kim-Anh Tempelman.
For further information see: FAO (2007b).

traditional production systems are threatened, progress can be made towards the achievement of goals such as, managing communal grazing areas, improving genetic resources and strengthening social development. However, the example from Nepal (Box 103) shows that as production conditions change, the introduction of imported genetic resources can sometimes be a viable option for small-scale livestock keepers. While in this case the livelihoods of the farmers have been improved, the local buffalo genetic resources are no longer being utilized. The example illustrates that achieving strategies that simultaneously improve livelihoods and achieve conservation objectives will often be a challenge.

Although *in situ* conservation is the most frequently adopted conservation method in Europe, there are also several examples of *ex situ in vivo* conservation programmes, in farm parks and in a few cases in zoos. In the United Kingdom there are currently 17 Rare Breeds Survival Trust Approved Centres[20]. One such farm, the Cotswold Farm Park[21], attracts over 100 000 visitors annually. In Germany, Falge (1996) reported 124 institutions maintaining animals of 187 breeds and nine livestock species. Similar institutions exist in many other parts of Europe, for example, in Italy, France and Spain, and also in North America. A particularly valuable role of farm parks is that they contribute to public awareness of AnGR conservation. For some species, such as poultry, enthusiastic hobby-breeder organizations play a role in conserving local breeds. The first example of a protected area focused on rare domestic breeds was in Hungary, where native breeds are conserved on the Puszta (an area of grassy wetlands and plains in eastern part of the country). Such schemes are now found in other parts of Europe and elsewhere.

In the developing world, the most commonly observed *ex situ in vivo* conservation activities are in herds or flocks maintained by state-owned institutions. The evidence provided by the Country Reports suggests that there is insufficient information to determine how sustainable such conservation programmes will be. It seems that virtually all *ex situ in vivo* conservation in the developing world is used to support ongoing use of the AnGR by farmers – raising the question of whether *ex situ in vivo* conservation is likely to be a viable approach to conservation of AnGR that are no longer in current use. There is very clearly a need to develop a far greater understanding of how to design and implement sustainable *in vivo* conservation, particularly in the developing world.

7 Current status and future prospects for cryoconservation

From the early development of AI in the mid-1940s to the most recent potential offered by DNA storage and transfer, reproductive biotechnologies have been instrumental in the transfer of genetic material *in vivo* and *in vitro*. The techniques that are currently accessible and economically feasible for *in vitro* conservation of AnGR are those for cryoconservation of reproductive cells, embryos and tissues. Materials conserved using these techniques may preserve their liveability and functional state for decades or even centuries. However, because of the relatively short period during which the technologies have been in existence, a precise evaluation of this putative longevity remains to be established. More recent biotechnologies, including cloning, transgenesis and transfer of somatic material, have great potential for future applications in AnGR conservation, but at present they are only accessible to a few laboratories. The low reliability and extremely high costs of these technologies are two factors likely to limit their use in AnGR conservation in the coming years. This chapter, therefore, focuses primarily on current state-of-the-art reproductive biotechnologies that are economically and technically accessible in most geographical areas.

[20] http://www.rbst.org.uk/html/approved_centres.html
[21] http://www.cotswoldfarmpark.co.uk

Previously published documents such as the "Guidelines for development of national farm animal genetic resources management plans" (FAO, 1998c) and "Guidelines for the constitution of national cryoconservation programmes for farm animals" (ERFP, 2003) provide more details about applications.

7.1 Gametes

Semen

Semen from all mammalian livestock species has been successfully frozen in past years, as has semen from some poultry species (chickens, geese). Freezing procedures for semen cryoconservation are species-specific, but the general procedures are as follows:

- following collection, semen is diluted in a suitable ionic (salt) or non-ionic (sugar) solution adjusted to near physiological osmolarity;
- suitable cryoprotectant is added – glycerol is most commonly used, but dimethyl sulfoxide (DMSO), dimethylacetamide (DMA) or dimethylformamide (DMF) are, depending on the species, of high practical interest;
- diluted semen is cooled, sampled and then frozen in liquid nitrogen (-196 °C);
- individual semen doses are generally frozen in straws rather than pellets to guarantee optimal sanitary conditions and permanent identification of each dose.

Following AI with frozen and thawed semen, global conception rates average 50–65 percent in more than 110 million yearly first-service inseminations in cattle; 70–80 percent in more than 40 million inseminations in pigs; 50–80 percent (intrauterine) or 55–65 percent (cervical) in more than 120 000 inseminations in goats; 50–80 percent (intrauterine) or 55–60 percent (cervical) in more than 50 000 inseminations in sheep; and 35–40 percent in more than 5 000 inseminations in horses (Ericksson *et al*., 2002; Thibier, 2005; G. Decuadro, personal communication, 2005). Results in chickens reveal large between and within-breed variability in the range of 10–90 percent (Brillard and Blesbois, 2003).

The number of semen doses that need to be stored is a function of the number of doses required per parturition or hatching, the expected lifetime production of fertile refounder females, and the number of males and females desired in the reconstructed population. Where semen is used to reconstruct breeds by backcrossing, some percentage of the genes from the female population used in the backcross will remain in the reconstructed breed. For example, five generations of backcrossing are needed to obtain animals carrying over 95 percent of the genotype of the breed restored from the frozen semen. Sufficient semen must be stored to produce the number of backcross generations required. In avian species in which females bear ZW heterochromosomes (males are ZZ), genes carried by the W chromosome cannot be transferred through standard semen cryoconservation. Moreover, in all species, some cytoplasmic effects of the donor breed may be lost or altered. Notwithstanding these limitations, this technique should be seen as playing a predominant role in the *ex situ in vitro* conservation of AnGR, because of the availability of advanced and reliable technology and the ease of application. However, if the number of doses available per male is low or if the number of females that can be obtained per dam is low, then the re-establishment of the breed via embryo transfer is, where possible, more desirable as a means of ensuring full recovery of the initial genes.

Oocytes

In the case of birds, despite interesting technical developments, hatched chicks have not yet been successfully obtained from eggs that have been frozen and thawed. This is, in part, because of the huge amount of lipid present in the vitellus. In contrast, embryos from some mammalian livestock species can be produced *in vitro* from matured oocytes collected at slaughter or from live females by ovum pick-up. Such oocytes can be frozen for prolonged periods prior to *in vitro* fertilization (IVF) to produce embryos. Two methods of freezing can be distinguished based on the rapidity of the freezing procedures. Slow-freezing procedures are currently feasible in cattle and potentially applicable in sheep and goats, but success rates in obtaining progeny remain extremely low (less than 10 percent). In part, this is a result of the limited success rate of embryo transfer, and high embryo mortality following fertilization. Moreover, such techniques, which require oocyte maturation prior to IVF, must be performed by highly qualified technicians. Ultra-rapid freezing procedures, also called vitrification, are currently developed experimentally to limit damage to the oocyte resulting from chilling injuries or the toxicity of cryoprotectants. Most protocols use high concentrations of cryoprotectants and sugars to remove water from the cells. This limits intracellular ice formation and, therefore prevents ice injuries to the oocyte. Promising results have been obtained in cattle. However, working procedures which would make the cryoconservation of oocytes useful for the preservation of AnGR remain to be validated on a large scale.

7.2 Embryos

In contrast to avian species, embryos of virtually all mammals can be successfully frozen, thawed and then transferred into recipient females to produce progeny. Currently, however, widespread use of embryo cryoconservation is limited to cattle, sheep and goats. Embryo collection in pigs requires the sacrifice of the female, and the procedure remains experimental in equine species. A number of factors including the method of embryo collection (biopsied, produced *in vitro*, or cloned), and stage of maturation, greatly affect the probability of obtaining live progeny. A variety of protocols to freeze and thaw embryos from livestock have been proposed, and as in the case of oocytes, they can be classified into two major categories based on the rapidity of freezing procedures.

In slow freezing approaches, equilibration of cryoprotectants and solutes between the medium surrounding the embryo and its intracellular compartments occurs slowly, thus limiting the risks of membrane rupture due to intracellular ice formation. Upon thawing, embryos are transferred into recipient females with or without removal of the cryoprotectant. Internationally, such techniques are at present the most commonly used in cattle, sheep and goats. Success rates at parturition vary depending on the species, genetic origin, source (*in vivo* or *in vitro*), and stage of development of the embryos. Embryos cryoconserved at an early stage of their development result in lower parturition rates than embryos cryoconserved at a more advanced stage (Massip, 2001).

Fast freezing (vitrification) techniques involve ultra-rapid cooling and freezing of embryos in a very small amount of suspending medium in which cryoprotectant and other solutes (sugars) are generally at high concentrations. Embryos from several mammalian species (cattle, sheep and goats) have been successfully vitrified and transferred. Survival rates of 59 and 64 percent have been observed in sheep and goat embryos, respectively, using the so-called pulled-straw vitrification technique (Cognié *et al*., 2003).

Embryo preservation techniques are of particular interest with respect to the cryoconservation of AnGR because they allow full recovery of the initial genome. Slow freezing rates require expensive programmable freezers, but offer more flexibility to untrained technicians because of the relatively long intervals between the two steps of the procedure. In contrast, vitrification requires only limited equipment, but highly trained technicians.

7.3 Cryoconservation of somatic cells and somatic cell cloning

Since the creation of Dolly the sheep, the first animal created by cloning of somatic cells, the technology has been shown to work for most mammals in which it has been tested, However, it has not been applied successfully in birds. The current state of the technology is costly, with extremely low success rates. If reconstitution of live animals from somatic cells is developed to the point where it becomes both reliable and cheap, preservation of somatic cells would become an attractive option for cryoconservation of AnGR. Its main advantage would be that it would be possible to choose exactly which animals to conserve, and later to reconstitute a population of clones of these animals. Unlike in the case of preserved embryos, the cytoplasmic DNA is not preserved in animals derived from somatic cells. Collection of somatic cells is, however, far simpler than collection of embryos, and it would be feasible to collect samples extensively from field populations. The current costs of developing somatic cell cultures, and uncertainty about

TABLE 105
Current status of cryoconservation techniques by species

Species	Semen	Oocytes	Embryos	Somatic Cells
Cattle	+	+	+	+
Sheep	+	0*	+	0
Goat	+	0	+	0
Horse	+	0	0	0
Pig	+	0	0	0
Rabbit	+	0	+	0
Chicken	+	-	-	-

+ routine techniques available; 0 positive research results; - not feasible in the current state of art; * cryoconservation of the whole ovary.

Box 104
Revival of the native Red and White Friesian cattle in the Netherlands

In 1800, the cattle population in the province of Friesland consisted mainly of Red Pied cattle. Many red ancestors were imported from Denmark and Germany after widespread losses caused by rinderpest. Since 1879, the Friesian Cattle herd book had registered a Red and White phenotype, but pushed by export markets, black and white animals progressively became more popular than the original red and white. In 1970, only 50 farmers owning a total of 2 500 cattle joined the Association of Red and White Friesian Cattle Breeders. Within a short period, the sustained import of Holstein-Friesians from United States of America and Canada resulted in a further decline of the population, so that only 21 Red and White individuals (4 males and 17 females) were remaining in 1993. A group of owners started the Foundation for Native Red and White Friesian Cattle. In collaboration with the newly created Genebank for Animals, a breeding programme was developed. Semen from sires preserved in the genebank in the 1970s and 1980s was used to breed females under a contract system. Male progeny were raised by breeders, who were granted a subsidy from the genebank. Semen from these males was collected, frozen and later used under new contracts. The breed increased in number, reaching 256 registered living females and 12 living males in 2004. Currently, a total of 11 780 semen doses from 43 bulls are stored in the genebank and kept available for AI. The majority of cows are raised by hobbyists for milk production.

Provided by Kor Oldenbroek.

Box 105
Revival of the Enderby cattle in New Zealand

The case of the Enderby Island cattle illustrates that it is possible to resurrect breeds from extremely limited genetic material. However, it also shows that the process is complicated and requires a lot of time and resources.

Enderby is a small island situated 320 kilometres to the south of New Zealand. Cattle were first brought to the island in 1894, when one W.J. Moffett of Invercargill took up a pastoral lease and landed nine shorthorns. By the 1930s, farming on the island had been abandoned, but the cattle remained as a feral herd. After 100 years surviving Enderby's harsh climate and a diet of scrub and seaweed, the cattle were hardy, small, stocky and well adapted. In 1991, to help preserve the local wildlife, the Enderby cattle were shot. Sperm and oocytes from the dead animals were collected for cryoconservation, but attempts to fertilize the oocytes failed and it appeared that the Enderby breed had been wiped out forever.

The following year, members of the New Zealand Rare Breeds Conservation Society (NZRBCS), discovered a cow and a calf on the island. The animals were captured by helicopter and shipped to New Zealand. The subsequent death of the calf meant that "Lady", as the cow became known, was the last of the Enderby cattle. Attempts to produce a calf, through artificial insemination and MOET, using the cryoconserved semen taken from the bulls killed on the island, did not prove successful. Again it appeared that the breed faced extinction. However, in 1997 NZRBCS in collaboration with AgResearch successfully produced a calf, Elsie, cloned from a sample of Lady's somatic cells. Four more cloned heifers were born the following year. Meanwhile, efforts to produce an Enderby bull through *in vitro* fertilization using the cryoconserved semen and oocytes taken from Lady had also proved successful, with the birth of "Derby". Two of the clones later died, but in 2002 two more Enderby calves were born through natural mating of the cloned heifers and Derby.

For more details see: Historical Timeline of the Auckland Islands; NZRBCS, (2002); Wells, (2004).

future prospects for producing live animals from the preserved cells, mean that somatic-cell conservation is unlikely to be a priority in species where cryoconservation of gametes and embryos is well developed. However, cryoconservation of somatic cells would be a prudent back up where cryoconservation of gametes and embryos is not feasible or has low success rates.

Table 105 provides an overview of the feasibility of the above-discussed techniques in the major livestock species.

7.4 Choice of genetic material

Techniques to cryoconserve gametes and embryos are, extensively used for commercial purposes in most domesticated mammals; there are a few exceptions such as transfer of frozen embryos in equines and pigs (Thibier, 2004). In the case of cryoconservation programmes devoted to AnGR management, one major issue is to store sufficient biological material to allow the reconstruction of individual animals or populations bearing the desired traits. The choice of donor origin, number of donor individuals and type of material to be cryoconserved are, therefore, crucial if investments are to be of long-term benefit. Useful recommendations regarding these matters are available from the following sources: Blackburn (2004), ERFP (2003) and Danchin-Burge *et al*. (2002).

7.5 Security in genebanks

Genebanks for AnGR germplasm must provide technically secure storage and meet strict zoosanitary requirements.

Technical security
Loss of liquid nitrogen for any period of time (literally minutes) can lead to complete loss of the cryoconserved material. Storage of cryoconserved materials in two separate containers, and preferably two separate locations, limits the risk of losses resulting from accidental failure to maintain liquid nitrogen.

Biosecurity
Materials of animal origin including fluids, gametes and embryos may carry pathogens capable of surviving cryoconservation. While additional research is needed to further assess risks of transmission through genebanking, biosecurity recommendations provided by the Terrestrial Animal Health Code of the World Organization for Animal Health (OIE) are universally applicable. Meeting the requirements of the code presents severe difficulties for many countries. It makes movement of germplasm from disease-affected to disease-free areas extremely difficult. It can also mean that samples that do not meet the code's requirements cannot be stored in the same facility as samples that do. Such issues could provide a substantial obstacle to the establishment of national, regional and international cryoconservation banks. Special structures and possibly some special exemptions to existing codes will be required.

8 Resource allocation strategies in conservation

8.1 Methods for setting priorities

A clear definition of objectives is crucial for all conservation activities. One criterion that will often be considered important is the preservation of genetic diversity. However, conserving as much diversity as possible will rarely be the sole objective. Other factors such as conservation of certain special traits (e.g. disease tolerance), and ecological or cultural values of breeds, also have to be taken into account. The objective is, therefore, to maximize the utility of a set of breeds, where utility is a weighted combination of measures of diversity and other traits/values. Definition of weights requires the valuation of diversity relative to the other criteria considered.

Another important consideration is the degree of endangerment of the breeds in question. This can be quantified in the form of an extinction probability. The parameter is mainly determined by the effective population size, and the demographic trend (i.e. whether the population size is increasing or decreasing), but should also take into account other factors such as geographic distribution, implementation of breeding programmes, specific ecological, cultural or religious functions, and risk from external threats (Reist-Marti *et al*., 2003).

Various methods for combining different criteria have been proposed for prioritizing breeds to be targeted by conservation programmes. Ruane (2000), for example, proposed a method to be followed by a group of experts identifying breed priorities at the national level. The following seven criteria are included in the framework:

- species (i.e. breeds from which species are to be included in the priority setting exercise?);
- degree of endangerment;
- traits of current economic value;
- special landscape values;
- traits of current scientific value;
- cultural and historic value; and
- genetic uniqueness.

It is suggested that breeds with high degrees of endangerment should be given priority. If it is necessary to prioritize among highly endangered breeds, it is then suggested that the extent to which the breeds meet the other listed criteria should be taken into account. It may be necessary to assign weights to the various criteria in order to allow further differentiation of priority ranks. The relative importance to be given to each criterion would be decided by the expert group.

Hall (2004) put forward a framework based on both genetic and functional diversity, using

British and Irish breeds of sheep and cattle as an example. Each breed under consideration was compared to every other breed in terms of functional and genetic distinctiveness. The genetic component was assessed on the basis of the history of the breed and the likelihood of significant gene flow within the last 200 years. The functional component related to the economic, social and cultural functions of the breed. In cattle, functional distinctiveness was assessed subjectively, but this was more difficult to do in the case of sheep. As such, mean fibre fineness, almost the only parameter that had been measured in a comparable way across the breeds in the study, was used as an indicator of functional distinctiveness in sheep breeds. Breeds that scored highly both for functional and genetic distinctiveness were considered to be the most appropriate for inclusion in a list of priorities.

The Rare Breeds Survival Trust in the United Kingdom has also established a set of criteria for recognition of "rare breeds" which require special attention in terms of conservation measures (Mansbridge, 2004). The length of time for which a breed has existed, the number of female animals, and the breed's geographical distribution are taken into account.

8.2 Optimization strategies for planning conservation programmes

Efficient conservation programmes should use available monetary or non-monetary resources in such a way that the conservation objective is maximized. The questions to be answered are:

- For which breeds within the species under consideration should conservation programmes be implemented?
- What share of the total conservation budget should be allocated to each of the chosen breeds?
- Which conservation programmes should be implemented for any chosen breed?

If it is assumed that the objective of the conservation measures being considered is to conserve as much genetic diversity between breeds as possible, then the following method may be used to identify priority breeds (Simianer, 2002).

The total diversity of an existing set of breeds can be calculated, as can the contribution of each breed to the total diversity. Extinction probabilities and the diversity of different subsets of breeds are used to calculate what is referred to as the "expected diversity" (Box 106). This is the diversity expected at the end of the planning horizon assuming that no conservation activities are undertaken. It may happen that at the end of the planning horizon some of the most endangered breeds will have become extinct. If, however, conservation efforts are undertaken, the extinction probability of breeds will be reduced and the expected diversity will increase. The amount of change in the expected diversity as a function of the change in the extinction probability of a particular breed is referred to as the breed's "marginal diversity". This marginal diversity reflects the breed's phylogenetic position. It also indicates whether closely related breeds are safe from extinction, but is independent of the breed's own extinction probability.

The conservation priority of a breed has been shown to be proportional to its "diversity conservation potential" (Box 106) – a measure which reflects the additional amount of diversity that would be conserved if a breed were made completely safe from extinction. A high conservation potential can either result from a high degree of endangerment, or from a high marginal diversity.

The parameters discussed here (marginal diversity, conservation potential, etc.) are elements of the general diversity theory put forward by Weitzman (1992; 1993), which has attracted considerable interest as a framework for decision-making in livestock conservation. The approach does not require that Weitzman's diversity metric, which is diversity between breeds, is the quantity maximized. The methodology can be applied to any objective function, including more comprehensive diversity metrics or utilities (in the sense of a weighted sum of a diversity component and other values).

Box 107 describes an example in which an optimum allocation of conservation funds could increase cost efficiency by almost 60 percent compared to that achieved using simplistic approaches.

Defining conservation priorities by ranking breeds according to their conservation potential assumes that conservation costs are roughly identical between breeds. More precisely, the assumption is that opportunity costs for the reduction of the extinction probability by one unit are uniform across breeds. This of course is not true: reducing the extinction probability from, say, 0.8 to 0.7 (i.e. by 12.5 percent) can be achieved by relatively simple means and is much cheaper than reducing the extinction probability from 0.2 to 0.1 (i.e. by 50 percent).

For a more detailed and realistic analysis it is necessary to define the cost of particular conservation activities (e.g. establishing cryoconservation, or giving subsidies to farmers to maintain an *in situ* population of a breed at risk), and also to assess the effect of such activities in terms of a reduction in the extinction probability of the respective breed. If allocation of resources is undertaken in an international context, different cost levels, technical standards, and currency exchange rates need to be taken into account: it may well be the case that cryoconservation is established as a routine application in one country, while in another country, the required infrastructure would first have to be developed. Another consideration is that labour costs for *in vivo* conservation schemes may differ substantially between countries.

A conservation scheme always has a number of costs, which will vary markedly between species and countries. The fixed costs are those required to establish and run the scheme as such (e.g. establishing a cryoconservation centre), while variable costs depend on the number of animals included and the type of genetic material (semen, oocytes or embryos) conserved in the scheme. Different conservation schemes vary in terms of the level of the fixed cost and the variable cost per genetic unit conserved. If this

Box 106
Glossary: objective decision aids

Diversity: numeric quantification of the amount of genetic variability in a set of breeds, ideally covering both the diversity within and between breeds.

Utility: numeric quantification of the total value of a set of breeds, e.g. a weighted sum of diversity and various economic value components.

Diversity contribution: the amount that the existence of a breed contributes to the diversity of the whole set of breeds.

Extinction probability: the probability that a breed becomes extinct within a defined planning horizon (often 50 to 100 years). The extinction probability can take values between 0 (breed is completely safe) and 1 (extinction is certain).

Expected diversity: the projection of the actual diversity to the end of a planning horizon, combining the actual diversity with extinction probabilities. The expected diversity reflects the amount of diversity to be expected if no conservation efforts are made.

Marginal diversity: reflects the change of expected diversity of the total set of breeds if the extinction probability of a breed is modified (e.g. through conservation measures).

Diversity conservation potential: a quantity proportional to the product of the marginal diversity and the extinction probability. This parameter approximately reflects how much the expected diversity can be increased if a breed is made completely safe. Weitzman (1993) suggested that this measure is the "single most useful [breed] alert indicator".

If utility rather than diversity is to be maximized, "utility contribution", "expected utility", "marginal utility" and "utility conservation potential" are the relevant terms, and the word "diversity" in the above definitions should be replaced by "utility."

Source: adapted from Simianer (2005).

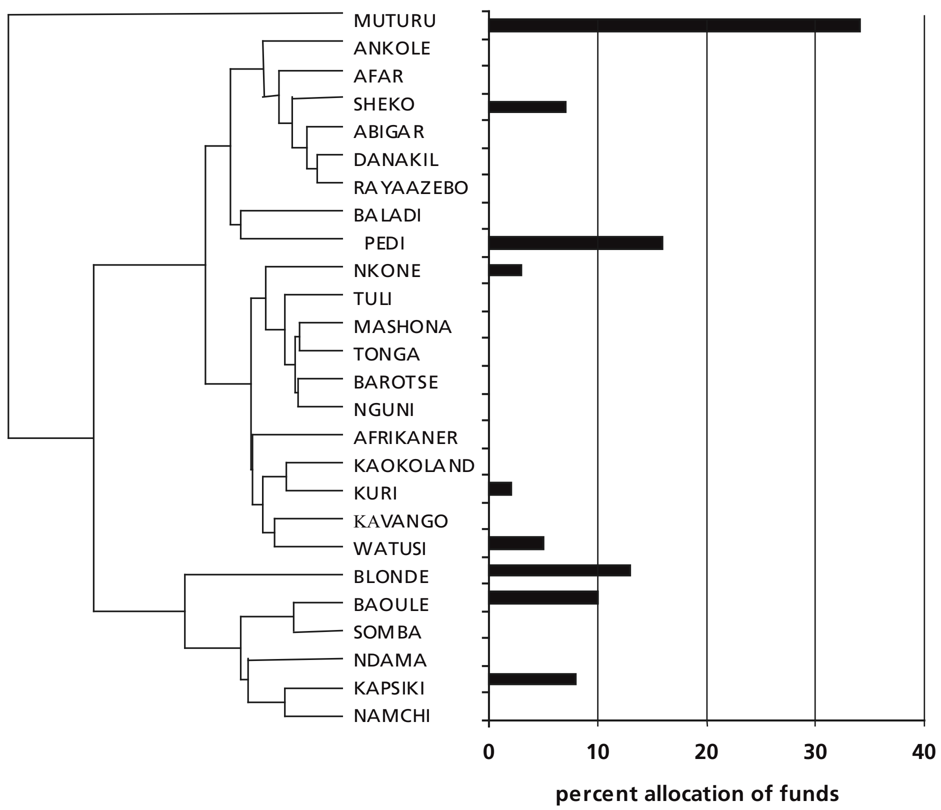
Box 107

Optimum allocation of conservation funds – an example featuring African cattle breeds

Simianer (2002) illustrated the application of an optimum allocation scheme to a set of 26 African taurine and Sanga cattle breeds for which estimates of genetic distances (based on 15 microsatellites) and extinction probabilities had been calculated. Using the extinction probabilities, the expected loss of diversity in the absence of conservation over the assumed planning horizon of 50 years was estimated to be 43.6 percent of the current diversity. It was assumed that a conservation budget was available which, if allocated equally across all breeds, would prevent 10 percent of the expected loss of diversity. If this same total budget is allocated to the conservation of only the three most endangered breeds, the diversity conserved decreases slightly to 9 percent of the expected loss, and so is 10 percent less efficient than allocating funds equally across breeds. With an optimum allocation scheme based on Weitzman's diversity concept, 10 of the 26 breeds receive funds, with 34 percent of the funds being used for Muturu and only 2 percent for Kuri (see figure).

With the optimum allocation strategy, the expected loss of diversity is reduced by 15.7 per cent. This is 57 percent more efficient than allocating funds equally across breeds. The same impact on diversity as the uniform allocation strategy could be achieved with an optimum allocation of only 52 percent of the available funds. The example illustrates that optimum allocation can substantially increase the efficiency of use of conservation funds.

Provided by Henner Simianer.



cost structure can be modelled with sufficient accuracy, optimum allocation schemes will not only assign a share of the conservation budget to a certain breed, but will also indicate which of the available conservation techniques will be most cost effective for this breed.

Since optimum allocation procedures are based on mathematical optimization, it is relatively simple to include certain restrictions or side conditions. This could relate to geographic balance, i.e. require that conservation activities are implemented in all parts of the target region. It could also force the optimum solution to avoid the loss of certain special traits by putting a high penalty on solutions in which, for example, all trypanotolerant cattle breeds become extinct.

Other strategies to find the optimum pattern of resource allocation are restricted to more specific decision-making problems. Eding *et al.* (2002) suggested the selection of a so-called core set of breeds based on marker estimated kinships. A core set can be thought of as a live or cryoconserved mixed population, which is constituted of various proportions of different breeds. The breed contributions to the core set are derived in such a way, that the expected diversity of the total core set is maximized. The advantage of this approach is that it combines between and within-breed diversity. However, it does not take into account the degree of risk faced by particular breeds, which limits its usefulness to special cases of decision-making, such as finding the optimum design for a cryoconservation programme with limited storage capacity.

Resource allocation for the efficient conservation of AnGR diversity requires good information on the phylogenetic substructure of a species, on factors affecting the degree of threat faced by the breeds considered, and on any special values that the breeds may have. A substantial knowledge of potential conservation programmes, including their costs, is also required. The more complete and reliable this information, the more cost effective the design of the optimum conservation programme will be. Further work is required to resolve the question of what are the most appropriate factors to be optimized in conservation efforts, because use of different factors may lead to different conservation decisions. Substantial further work is also required to develop tools that will assist the maximization of a diverse range of measures of diversity and utility.

Final decisions on investments in conservation will be driven by many economic, social and political factors. Thus, the decision-aids described above should be regarded as tools to allow decision-makers a better understanding of the consequences of alternative investment strategies for conservation.

9 Conclusions

Traditions and cultural values are important driving forces for conservation in Western societies, and are also becoming increasingly important in some developing countries. Another strong motivation that is shared by many stakeholders is safeguarding as much diversity as possible for an unpredictable future.

Conceptually, the most basic unit of diversity is the allele, and thus, from a scientific point of view, one definition of maintaining genetic diversity could be considered to be maintaining high allelic diversity. This would avoid the problems associated with scientifically defining a breed. At present, however, molecular measures of genetic diversity provide only indirect indications of genetic diversity in functional or potentially functional regions of the DNA. Thus, the best proxy for functional diversity remains the diversity of breeds or distinct populations that have developed in distinct environments, and possess different production and functional traits. Furthermore, cultural arguments for conservation are linked to breeds not to genes. Nevertheless, there is a need to develop objective criteria to decide whether a certain breed is of unique scientific value, or whether, for example, it could be substituted by a neighbouring population. This requires the combination of all available information on breed characteristics, origin and geographical distribution. Wherever possible, additional information, including results from molecular characterization, should be also considered.

In vivo and *in vitro* conservation methods are clearly distinct in terms of what they can achieve. Preserving live animals allows further evolution of the breeds in interaction with the environment, while *in vitro* conservation preserves the current genetic status. *In vitro* methods provide an important back-up strategy when *in vivo* conservation cannot be established or cannot conserve the necessary population size. It may also be the only option in the case of emergencies such as disease outbreaks or wars. The past focus on cryoconservation as a supporting tool for breeding programmes has led to technically sound solutions for the main livestock species. However, there is an urgent need to develop standard procedures for all livestock species. Freezing tissue samples seems an appealing method, because of the ease with which the genetic material can be sampled. However, the difficulty of reproducing living animals from these samples suggests that it should be regarded as a method of last resort.

It is interesting to note that it has long been accepted that international genebanks financed by the international community should preserve plant genetic diversity. The Global Trust Fund Initiative aims to create the framework for long-term financial support for these genebanks to make them independent of the short-term financial priorities of the host institutions. Furthermore, the Norwegian government has offered to provide a last resort for PGR, which will be put in place in 2007 (Box 108).

In general, it takes much longer to create a livestock breed than to create a plant variety – for some breeds it has taken centuries. However, the global community seems to be much less prepared to invest the necessary time, energy and money in safeguarding this heritage. Nonetheless, it is a global responsibility to ensure that valuable resources are maintained – a responsibility that includes all genetic resources for food and agriculture.

The analysis of *in vivo* conservation methods indicates that the distinction between *in situ* and *ex situ in vivo* conservation methods is not clear cut. It may, therefore, be appropriate to consider *in vivo* conservation methods as a continuum: ranging from conserving animals in their original production environment, (*in situ* conservation as defined above), to the extreme *ex situ* situation of conserving livestock breeds in zoos. While there is clearly a preference for maintaining livestock breeds in the production environments, in which they were developed, it is important to carefully evaluate whether conservation objectives might also be achieved in an *ex situ* context. This will clearly depend on the species and on the specific *ex situ* conditions. In the developing world, most reported examples of *ex situ* conservation are linked to *in situ* populations, and it appears doubtful whether they are independently viable.

While methodologies to maintain maximum diversity in small populations have been developed, implementation strategies for maintaining at-risk breeds in traditional production systems are rare. Various successful examples have been reported from developed countries and from some developing countries. In developed countries, several possibilities, such as niche markets, conservation grazing or subsidies, have been employed to increase the economic viability of endangered breeds. Conversely, in developing countries the only successful examples reported are linked to consumer or market demands for specific or traditional products. However, these practical examples of what has been achieved have not yet led to (scientific) concepts or models for implementation strategies. Furthermore, no reliable estimates of the costs and benefits of conservation strategies are available. Attempts to optimize the allocation of conservation funds are based on crude assumptions on the cost side, and use rather simplistic objective functions. The development of more complex objective functions is constrained by the difficulties of quantifying desirable functional traits to be included.

Box 108
The Svalbard Global Seed Vault: an international seed depository in the Arctic

The Government of Norway recently initiated planning for the construction of the Svalbard Global Seed Vault to serve as an ultimate "fail-safe" back-up facility for genebanks. The facility will be established near the town of Longyearbyen, on Svalbard, at 78 degrees North and will open in the spring of 2008.

The depository will be large enough to conserve a copy of all distinct accessions now held in genebanks around the world, with additional space available for new collections. It will be located in a "vault", carved out of solid rock inside a mountain, and lined with reinforced concrete. There will be an air-lock door for moisture control, and a number of robust security devices. The remote location, the presence of Norwegian authorities, and the occasional wandering polar bear, will combine to make this facility the most secure and reliable in the world. Under normal conditions, collections will be housed at approximately -18 °C. However, as the vault will be located in permafrost, long-term electricity failures would only result in the temperature gradually rising to -3.5 °C.

The town of Longyearbyen, a dropping-off point for expeditions to the North Pole, is served by daily flights, and has excellent infrastructure and power supplies utilizing locally procured coal.

The seed depository will not be a "genebank" in the normal sense of the term. Instead, it will be intended to house distinct accessions that are already conserved and duplicated in two traditional genebanks that would serve as the source of seed for plant breeders and researchers. Materials from the depository, stored in "black-box" conditions, would be available only when all other copies had been lost, in keeping with the intention of providing a safe and secure facility that could provide protection for plant genetic resources for food and agriculture in the case of large-scale catastrophes such as nuclear war, or major acts of terrorism.

Participation in the scheme will be purely voluntary. Management will be "passive" the depository will not engage in characterization, evaluation, regeneration or other similar activities. The Nordic Gene Bank will be responsible for placing materials in the depository and retrieving them as necessary. It already has its back-up collection in another facility at Svalbard, and duplicate collections from SADC are also currently stored there. Due to the necessity of keeping management operations and costs at a minimum, and in keeping with the intention of constructing a facility that will function without day-to-day human involvement, the depository will only be in the position to accept properly packaged orthodox seed. As the facility will be designed for the international community, Norway will not claim any ownership over the seeds stored there.

The FAO Commission on Genetic Resources has warmly welcomed the Norwegian initiative, and many countries, as well as centres of the CGIAR, have already signalled their desire to make use of the depository.

Provided by Cary Fowler.

The scientific concepts which are available for certain aspects of conservation have been developed mainly in the context of breeding programmes. Genuine research in the field of conservation of livestock genetic diversity (probably with the exception of molecular methods) is still in its early stages.

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