Part 4

STATE OF THE ART IN THE MANAGEMENT OF ANIMAL GENETIC RESOURCES

Introduction

This part of the report gives an overview of the state of the art in methodologies and techniques for the management of animal genetic resources for food and agriculture (AnGR). As AnGR management is not an established scientific discipline, Section A outlines basic concepts that underlie FAO's understanding of the term. These concepts are the outcome of a series of expert meetings. Methodological developments in relevant fields of research are then highlighted, and important findings are illustrated through case studies. Finally, gaps in current knowledge are identified, and priorities for future research are proposed.

Section A

Basic concepts

1 Animal genetic resources and breeds

AnGR are here defined as those animal species that are used, or may be used, for food production and agriculture[1], and the populations within each. Distinct populations within species are usually referred to as breeds. The broad definition of the term "breed" used by FAO (Box 67) is a reflection of the difficulties involved in establishing a strict definition of the term.

Box 67
Definition of breed adopted by FAO

Either a subspecific group of domestic livestock with definable and identifiable external characteristics that enable it to be separated by visual appraisal from other similarly defined groups within the same species or a group for which geographical and/or cultural separation from phenotypically similar groups has led to acceptance of its separate identity.

Source: FAO (1999).

In developed countries, breeds are relatively clearly delineated. The role of breed societies, normally voluntary organizations, which supervise breeding standards, provide for the registration of animals, and promote the utilization of the breed, is important in this respect. A pattern of breed development based on recorded breeding and shared pedigrees emerged in western Europe during the late eighteenth century, with the first breed societies being established in England during the nineteenth century. Under the auspices of such organizations, a breed has come to be distinguished as a population sharing common ancestry, which has been subjected to similar selection objectives, and which conforms to certain established "breed standards".

Breeds are generally not completely isolated in genetic terms. They are constantly required to change in response to changes in market demand, and will at times be supplemented with bloodlines from other breeds (FAO, 2003). Moreover, despite the existence of societies ostensibly associated with specific breeds, the precepts to be followed when establishing criteria for the delineation of a breed remain vague. Definitions of breeds within a developed-country context have included "animals which share a common pattern of use in agriculture, a degree of uniformity of phenotype, and a common gene pool" (FAO, 1995) and "distinct intraspecific groups, the members of which share particular characteristics that distinguish them from other such groups" (FAO, 2003). Discussing the situation in the United States of America, Hammak (2003) notes that all that is required to start a breed

[1] Fish are excluded as management requirements and breeding techniques are very different. The term "farm animal genetic resources", which had been used by FAO in relation to the Global Strategy for the Management of Farm Animal Genetic Resources, has been criticized on the grounds that it appeared to exclude animals not kept on farms, but in mobile systems.

registry is "to adopt specific requirements for eligibility and start to record ancestry." Similarly, under European Union (EU) legislation, there is no definition of a "breed" beyond the requirement that in order to be registered as a pure-bred animal, an animal's pedigree should be traceable to "parents and grandparents ... which are entered or registered in a herd-book of the same breed ... [and the animal itself should be] ... either entered or registered and eligible for entry in such a herd-book" (the quotation, from Council Directive 77/504/EEC, relates to bovine animals, but similar rules apply to other species).

There may, indeed, be little benefit in seeking a perfect definition. In the words of Jay Lush, a prominent figure in the field of animal breeding and genetics,

> *"A breed is a group of domestic animals, termed such by common consent of the breeders, ... a term which arose among breeders of livestock, created one might say, for their own use, and no one is warranted in assigning to this word a scientific definition and in calling the breeders wrong when they deviate from the formulated definition. It is their word and the breeders' common usage is what we must accept as the correct definition"* (Lush, 1994).

In the developing regions of the world, the situation is even more complex, and the term "breed" often has little meaning. Populations that are isolated from others, whether on geographical, ecological or cultural grounds, will tend to become distinct as a result of natural and artificial selection, and genetic drift (FAO, 2003). However, the names used to distinguish livestock populations do not necessarily correspond to the underlying genetic diversity. In many cases, animals will not correspond to any recognized breed, although there may be local terms referring to different populations.

Where distinguishing genetically diverse populations is difficult, molecular studies may contribute to the delineation of separate breeds and breed groups. Studying the cultural and ecological aspects of livestock keeping also serves as a means of identifying populations that merit being treated as separate breeds. The following definition is an example of such an approach:

> *"A domestic animal population may be regarded as a breed, if the animals fulfil the criteria of (i) being subjected to a common utilization pattern, (ii) sharing a common habitat/distribution area, (iii) representing largely a closed gene pool, and (iv) being regarded as distinct by their breeders"* (Köhler-Rollefson, 1997).

Thus, in the absence of breed association records or molecular studies, the views of the livestock keepers themselves perhaps provide the best indicator of breed identity. It may be possible to identify groups of farmers who claim to be raising an animal of a distinct type; can reliably recognize the type; exchange germplasm only with other breeders dedicated to holding the same type; and indicate that such breeding practices have been ongoing for many generations (FAO, 2003).

Within a breed there may be "stocks", "strains", "varieties", or "lines"; these terms which are often used interchangeably describe populations within breeds that are phenotypically distinct as a result of human selection. The term "ecotype" refers to a population within a breed that is genetically adapted to a specific habitat.

2 Management of animal genetic resources

Management of AnGR focuses on maintaining genetic diversity. However, most scientific methods and techniques within the animal sciences (e.g. animal husbandry, animal breeding or genetics) have not been developed with this focus. Thus, there is no well-defined set of methodologies encompassed by the phrase "management of AnGR". The overview presented here, therefore, selects the methodologies most relevant to the topic, guided by FAO's definition:

> *"AnGR management encompasses all technical, policy, and logistical operations*

involved in understanding (characterization), using and developing (utilization), maintaining (conservation), accessing, and sharing the benefits of animal genetic resources" (FAO, 2001).

As such, this part of the report includes descriptions of methodologies for characterization and conservation (Sections B and F); because of their increasing importance, methods for molecular characterization are presented separately from other aspects of characterization (Section C). However, when it comes to utilization – using and developing AnGR for agriculture and food production – no clear concept has emerged. It is, therefore, not possible to present a comprehensive description of the state of the art in utilization. Nonetheless, FAO has started to identify key elements of such a concept, using as a starting point the definition of sustainable use proposed by the Convention on Biological Diversity (CBD):

"Sustainable use is the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations" (Article 2 of the CBD).

To meet this objective FAO has proposed that:

- wise use of AnGR is possible without depleting domestic animal diversity;
- AnGR with high levels of adaptive fitness to the environment concerned should be used, and sound genetic principles deployed; and
- development of AnGR includes a broad mix of ongoing activities that must be well planned and executed for success, and compounded over time.

Thus, an important element of (sustainable) use of AnGR is to ensure that locally adapted breeds remain a functional part of production systems. Adaptive fitness traits, some of which may not yet have been discovered, are of particular importance, as they are genetically complex and cannot easily be achieved by selection over a short period of time. Use of AnGR inevitably includes development – AnGR are dynamic resources, changing with each generation in interaction with the physical environment and according to the selection criteria of their keepers. The proposed approach for genetic improvement is to base breeding efforts on locally adapted genetic resources. This will help to avoid the loss of breeds with unique attributes. Existing genetic variation in animals' ability to use locally available resources, survive, produce and reproduce under the conditions of medium-to-low input farming should be exploited by well-designed breeding programmes. Complementary measures such as improvement in the provision of feed and water, treatment of diseases and parasites, and the management of reproduction will also need to be considered in strategies to improve the performance of these breeds.

Thus, genetic improvement methods are central to the development of breeds. Scientific methods for breeding programmes have, however, been developed mainly in higher-input production systems, and under favourable infrastructural conditions. Breeding programmes do not usually include maintaining genetic diversity within and between breeds as an explicit goal. The state of knowledge in the field of genetic improvement is described in Section D.

Ideally, breeding programmes should be part of a holistic strategy with the goal of sustainably intensifying production systems to improve the livelihoods of the producers. Sustainable intensification has been put forward as the ideal way of improving production systems, and is defined as follows:

"Sustainable intensification of production systems is the manipulation of inputs to, and outputs from, livestock production systems aimed at increasing production and/or productivity and/or changing product quality, while maintaining the long-term integrity of the systems and their surrounding environment, so as to meet the needs of both present and future human generations. Sustainable agricultural intensification respects the needs and aspirations of local and indigenous people, takes into account the roles and values of their

locally adapted genetic resources, and considers the need to achieve long-term environmental sustainability within and beyond the agro-ecosystem" (FAO, 2001).

Addressing these general principles for the use and development of AnGR is not merely a matter of scientific methodology, but requires an effective combination of methodologies and techniques with appropriate development policies. To support policy development, economic analyses are needed to describe the economic importance of locally adapted breeds, in particular from the perspective of the smallholder; to define the value of livestock genetic diversity; and to compare different management strategies. An overview of economic valuation methods is presented in Section E.

Another difficulty related to the concept of utilization, is that of clearly distinguishing it from *in vivo* conservation. This problem arises due to the fact that sustainable use is considered the preferred method of maintaining AnGR. Thus, when conservation is defined in the broad sense of ensuring maintenance of all relevant AnGR, it includes sustainable use. However, a more operational definition, which allows a clearer delineation of the subject, and which is used in Section F on methods for conservation, is that conservation comprises actions that are required because the continued use of a particular genetic resource is threatened. The role of conservation is to ensure that unique genetic resources are available to farmers and breeders in the future, and consequently, conservation can be considered as part of an overall strategy to use AnGR in a sustainable manner to meet current and future human needs. To inform decisions regarding conservation strategies, it is important to have an estimate of current risk status (see below), and also to identify threats likely to affect the breed in the near future. The latter allows interventions, such as any breed development necessary to maintain the breed, to take place at a sufficiently early stage.

Accessing and sharing the benefits of AnGR (also components of FAO's definition of AnGR management) are key areas for policy development. Interdependencies among regions in terms of access to AnGR, and past and present patterns of exchange are described in Part 1 – Section C. Developments in biotechnology (described in Sections C and F) have facilitated exchange and use of genetic resources, have begun to detect genes regulating functional traits, and present new opportunities for the use of genetic material. Thus, they will play an important role in future patterns of access and benefit sharing (ABS). The contribution that methodologies developed in the social and political sciences can make to the formulation of adequate policies for ABS is, however, beyond the scope of this discussion.

3 Risk status classification

An assessment of the risk status of livestock breeds or populations is an important element in the planning of AnGR management. The risk status of a breed informs stakeholders whether, and how urgently, actions need to be taken. Gandini *et al*. (2004) define "degree of endangerment" as "a measure of the likelihood that, under current circumstances and expectations, the breed will become extinct." Accurately estimating degrees of risk is a difficult undertaking and incorporates both demographic and genetic factors.

Clearly, current population size is an important factor in determining risk status. A small population is at greater risk of being wiped out by natural disasters, disease or inappropriate management. However, a mere headcount of animals, or even of animals of breeding age, does not give the whole picture with regard to risk status.

Breeding between individuals sharing common ancestors tends to reduce the rate of allelic variation in the next generation. The genetic diversity of the population is, thus, reduced. The accumulation of deleterious recessive alleles may threaten the fitness of the population and negatively affect reproductive rates, thereby increasing the risk of extinction (Gandini *et al*., 2004; Woolliams, 2004). The extent of the risk is commonly expressed in terms of the rate of inbreeding (ΔF) in the population, which is a measure of the expected changes in gene frequencies in the population due to genetic drift (Woolliams, 2004). The rate of inbreeding is often inferred from the effective population size (N_e). As N_e goes up ΔF decreases, or more formally, $N_e = 1/(2\ \Delta F)$.

The value of N_e in a population is often approximated on the basis of the equation $N_e = 4MF/(M+F)$ where M and F are number of reproducing males and females. The method is based on the assumption that matings between these breeding animals are random. However, this assumption is rarely applicable in livestock populations, as some individuals contribute disproportionate numbers of progeny to the next generation. The way in which breeding is managed, for example the implementation of selective breeding programmes, influences the effective population size. Various techniques for adjusting the calculation to account for such factors have been developed, but require further data inputs (Gandini *et al*., 2004). Collecting the demographic data needed to calculate N_e is often problematic: there may be inconsistencies in census data and registration of females and offspring, some females may be used in crossing programmes, and not all females may be bred each year (Alderson, 2003). Another element that can influence the outcome of risk status estimations is the time interval over which risk is calculated. Because of the different generation intervals in different livestock species, calculations performed on the basis of the number of generations will produce different priorities from those calculated on the basis of years (ibid.).

Some implications of changes to the effective population size are important to note. At low levels of N_e, particularly below 100, the rate of loss of genetic diversity increases dramatically (FAO, 1992a). For example, approximately 18, 10, 4, 1.6 and 0.8 percent of genetic diversity is lost in ten generations, when N_e is equal to 25, 50, 125, 250 and 500, respectively (ibid.). Additionally, it can be seen from the above equation that the value of N_e is far more readily influenced by changes affecting the male (smaller) breeding population than the female. This underlines the importance of considering the number of breeding males in any assessment of risk status.

In addition to the current effective population size, degree of risk is related to population growth trends. As noted above, where populations are small there is a greater likelihood that adverse events or trends will lead rapidly to extinction. Above a certain population size the risk of such an outcome can be regarded as small (see below for discussion of the thresholds used in various risk status classifications). The more rapidly a population builds up to reach the critical size, the less it is exposed to the risk of extinction. Obviously, if population figures are low and the growth trend is negative, the prospects for the breed are not good. A complicating factor is that breed population growth rates often show considerable fluctuations over time, particularly where production conditions cannot be strictly controlled (Gandini *et al*., 2004). Factors which may influence the variance of the population growth rate include the variability of market demand, patterns of disease, the existence of programmes for and awareness of AnGR conservation, the general economic stability of the agricultural sector, and the spatial distribution and density of the population (ibid.). Calculating the probability that the population size will lie within a given range at a given time in the future is, thus, fraught with theoretical and data-related difficulties. Despite such problems, current population trends are clearly a factor to be considered in assessing risk status. In addition to overall population size and growth rates, the risk status of a population is affected by other factors such as the number of herds, and the geographical concentration of the population, which influence exposure to threats such as disease epidemics; and by sociological factors such as the age of the farmers keeping the breed (Woolliams, 2004).

In 1992, FAO convened an Expert Consultation to develop recommendations for the assessment of risk status. The preference was for a breed risk status classification based on the concept of N_e, adjusted by trends in population size, extent of cross-breeding, extent of cryoconservation, and variability of family size. It was also suggested that the number of herds and trends in the number of herds should be included (FAO, 1992a). However, data limitations and the necessity of a consistent approach on a global scale meant that a simpler approach was adopted, based on the number of breeding females and males, and trends in population size (see below for details). In the future, as more complete data become available it may be possible to refine the method of calculation to account for the above factors, and also to adapt it to account for the different generation intervals of different species.

For planning and prioritization purposes, it is useful to classify breeds into risk status categories. The numerical boundaries between the different risk status categories used by FAO are intended to be indicators of the need to take action. A paper presented at the Expert Consultation in 1992 argued that a population size between 100 and 1 000 breeding females "implies that the breed is in danger of extinction. Without action its effective population size is inadequate in most cases to prevent continuing genetic loss in future generations. An increase in the degree of inbreeding is unavoidable and threatens the vitality of animals. There is a real danger either of spontaneous loss for example by sudden disease, or due to neglect by man" (FAO 1992b). Further, a population size of less than 100 breeding females indicates that "The population is close to extinction. The first action must be to increase the population size. At this level of threat, the genetic variability is often already reduced so that the population cannot be considered the same as the ancient breed" (ibid.).

As such, the following classification is used by FAO to describe the degrees of risk faced by livestock breeds:

- Extinct breed: The case when it is no longer possible to recreate a population of the breed. Extinction is absolute when there are no breeding males (semen), breeding females (oocytes), nor embryos remaining.
- Critical breed: A breed where the total number of breeding females is less than 100 or the total number of breeding males is less than or equal to five; or the overall population size is close to, but slightly above 100 and decreasing, and the percentage of pure-bred females is below 80 percent.
- Endangered breed: A breed where the total number of breeding females is between 100 and 1000 or the total number of breeding males is less than or equal to 20 and greater than five; or the overall population size is close to, but slightly above 100 and increasing and the percentage of pure-bred females is above 80 percent; or the overall population size is close to, but slightly above 1 000 and decreasing and the percentage of pure-bred females is below 80 percent.
- Critical–maintained breed and endangered–maintained breed: Critical or endangered breeds that are being maintained by an active public conservation programme or within a commercial or research facility.
- Breed not at risk: A breed where the total number of breeding females and males is greater than 1 000 and 20 respectively; or the population size approaches 1 000 and the percentage of pure-bred females is close to 100 percent, and the overall population size is increasing.

The FAO system outlined above is not the only existing classification of risk status. Another classification was developed for the European Association of Animal Production–Animal Genetic Data Bank (EAAP–AGDB), and is now used by the European Farm Animal Biodiversity Information System (EFABIS) (http://efabis.tzv.fal.de/). It covers breeds of buffalo, cattle, goat, sheep, horse, donkey, pig and rabbit in 46 European countries, and is based on genetic risk – as represented by expected cumulative rates of inbreeding in

50 years (ΔF–50). Calculations are based on the familiar equation $N_e = 4MF/(M+F)$ (see above) with its inherent assumptions (EAAP–AGDB, 2005). Breeds are classified into one of five categories according to ΔF–50: not endangered, <5 percent; potentially endangered, 5–15 percent; minimally endangered, 16–25 percent; endangered, 26–40 percent; and critically endangered, >40 percent. Breeds may be shifted to a higher risk class based on a set of additional risk factors: a high rate of incrossing with other breeds; a downward trend in the number of breeding females; or a low number of breeding herds (ibid.).

The EU, under Commission Regulation (EC) No. 817/2004, sets out risk status thresholds for the purposes of providing incentive payments to farmers keeping threatened breeds. Calculations are based on the number of breeding females summed across all EU countries. Separate thresholds are established for each species: cattle – 7 500, sheep – 10 000, goats – 10 000, equidae – 5 000, pigs – 15 000 and avian species – 25 000. Some arguments can be put forward in support of these rather high thresholds. Gandini *et al.* (2004) note that while in the European context a breed with 1 000 or more breeding females can generally be self-sustainable, this is not always the case, and that it is easier to prevent a population from losing self-sustainability than to restore it.

The NGO Rare Breeds International has also developed a system based on the number of registered pure-bred breeding females, which classifies priority breeds into four categories: critical, endangered, vulnerable and at risk (Alderson, 2003). Other factors (number of breeding units, number of unrelated sire lines, population trends, distance between major breeding units), which would ideally be included in an estimation of risk status, are disregarded in the interests of avoiding excessive complexity in the calculations (ibid.).

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