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REVIEW

Conservation of breeds and maintenance of biodiversity: justification and methodology for the conservation of Animal Genetic Resources

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SUMMARY

Although the concept of genetic conservation has a long history it did not prevent the extinction of many breeds of domestic livestock. Significant intervention began to accelerate only in the mid-twentieth century through the work of both NGOs and governmental agencies. Endangered breeds now have been identified, catalogued and evaluated in most countries, and policies to maximise the maintenance of genetic diversity have been developed. The danger of irreversible breed substitution by dominant breeds is understood, and there is increasing awareness of the value of livestock with local adaptation.

Conservación de razas y mantenimiento de la biodiversidad: justificación y metodología para la conservación de los recursos genéticos animales

RESUMEN

Aunque el concepto de conservación genética tiene una larga historia, esto no ha evitado la extinción de muchas razas de animales domésticos. Las intervenciones significativas no comenzaron a acelerarse hasta mediados del siglo XX a través del trabajo tanto de las ONGs como de las agencias gubernamentales. Las razas amenazadas en la actualidad, ya están identificadas, catalogadas y evaluadas en la mayoría de los países, y las políticas para maximizar el mantenimiento de la diversidad genética han sido desarrolladas. El peligro de sustitución irreversible de razas locales por razas dominantes se ha comprendido, y hay un incremento del reconocimiento del valor del ganado con adaptación local. Una revisión de este reconocimiento y una descripción de las metodologías de conservación, caracterización y utilización se presentan aquí.

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INTRODUCTION

The global livestock industry experienced a fundamental change during the twentieth century. Until the end of the nineteenth century, genetic diversity in farm livestock had been maintained, or even increased. Thereafter, improved communications and transportation enabled more rapid movement of breeding stock around the world; greater understanding of genetics permitted increased selection intensity in breeding populations; and rapid advances in reproductive technology accelerated the speed of change.

The result has been a significant reduction in genetic diversity that is ongoing globally, and the Food and Agriculture Organisation (FAO) of the United Nations noted that in one region of the world, Europe and the Caucasus, the State of the World's Animal Genetic Resources survey documents "481 mammalian breeds (9 percent of all breeds listed) and 39 avian breeds (2 percent of all breeds listed) that have become extinct and another 624 mammalian and 481 avian breeds are at risk." (FAO, 2006).

The ultimate risk is extinction, but already most breeds have experienced genetic erosion because of either selection programmes or small population size or both. Popular mainstream breeds are not immune to the dangers of genetic erosion. The Holstein is the dominant dairy breed in the developed world, but its genetic development rests on a cohort of closely related bulls that threatens to reduce significantly the genetic variability of the breed.

However, the main emphasis of conservation programmes should be directed to those breeds which are seriously threatened and in danger of extinction. When FAO gave a broad over-view of the conservation of endangered breeds (FAO, 1998) it placed emphasis on the importance of native breeds, and primary responsibility for the conservation of a breed lies with its country of origin. Effective conservation programmes have been established in many countries, but there is not a consistent level of development, and native breeds in some countries may not be protected adequately.

The results of surveys of livestock breeds have been produced in several countries and regions, but the first comprehensive international survey was carried out by Mason and his dictionary was published in the mid-twentieth century (Mason, 1951). It eventually developed into an encyclopaedia (Porter et al, 2016) which provides valuable and detailed information for reference and research and includes an additional section on genetics and conservation. While recognising that programmes for genetic conservation should embrace all populations of livestock, this paper will focus primarily on endangered native breeds.

Justification for the conservation of endangered native breeds

Conservation of endangered native breeds involves more than genetics. It encompasses social, cultural and heritage factors, and local breeds are an integral part of the evolving diversity of a region. Justification for conservation programmes can be described in five categories, namely legal requirements which may be global or national, utility value in the livestock industry, value in scientific research, integral part of cultural heritage, and an insurance against changes in future requirements.

Legal requirement

Programmes for the conservation of genetic diversity during the second half of the twentieth century were driven primarily by NGOs. The first NGO to create a national plan was RBST in Britain, formed initially as a working group in the mid-1960s. It served as a model for many other national NGOs, but governmental programmes also were applied at an early stage in some countries such as Hungary. Governmental involvement became more common following a FAO technical consultation in Rome in 1980 (FAO, 1981) at which reports from countries as diverse as India, Kenya and UK showed that many conservation programmes already were well established. A major step forward was taken at the Convention on Biological Diversity (CBD) in Rio de Janeiro in 1992, which recognised the "special nature of agricultural biodiversity" (decision II/15) and to which more than 170 nations are signatories, and was firmly established on a global scale as a result of the State of the World Animal Genetic Resources (SoWAnGR) project initiated by FAO in 2002.

Meanwhile Rare Breeds International (RBI) had been established in 1989 as an 'umbrella' NGO to coordinate national members and worked in tandem with FAO. FAO directs much attention to the developing world, but FAO and RBI both are concerned by the growing threat to farm animal genetic resources (FAnGR) in developed countries from the global spread of a few specialised breeds, and take action to protect native FAnGR. The export of exotic breeds from developed countries to developing countries endangers native breeds and marginalises programmes to enhance and utilise their native adaptation.

The FAO Global Strategy for the Management of Farm Animal Genetic Resources is a governmental mechanism through which action is taken to protect native FAnGR and comply with CBD recommendations. A more recent Decision taken at the Conference of the Parties in Malaysia in 2004 (COP VII/3 on Agricultural Biodiversity) "*Invites* the Parties and other Governments to consider and promote, as appropriate and subject to national legislation and international law, the mainstreaming of agricultural biodiversity in their plans, programmes and strategies with the active participation of local and indigenous communities and the inclusion in the communities' plans, programmes and strategies on conservation, development and use of agricultural biodiversity - -".

Consequently, there now is a strong framework in place, endorsed by both governmental and NGO agencies, which not only permits future programmes to be developed, but also requires national governments to conserve their native FAnGR. This is intended to give underlying security for conservation of endangered native breeds.

Utility value

The strongest argument for the conservation of endangered breeds is their value in systems of livestock production. Breeds lose their place in mainstream agriculture either because of fashion, or because they no longer meet the current requirements of the marketplace. Fashion is a transitory factor, which does not guarantee ongoing popularity or viability. Similarly, inability to compete in the market place may be a short-term factor which will be corrected when consumer demand changes. On the other hand, it may be a more persistent problem if a breed declines to an unsustainable position before its market value can be identified.

The priority should be to evaluate the qualities of each breed and match them to appropriate functions and systems, but this outcome can be achieved only if its abilities have been identified through a programme of characterisation. The market place changes continually and a breed that could not compete in the past may be a strong competitor in the future. Current agricultural developments are causing major changes, and new opportunities are emerging in all regions. Understanding the value of local adaptation is vital in the developing world, while priorities in Europe changed in the wake of CAP reform, and climate change will create unknown challenges in all regions.

In particular, global warming and the damage caused by greenhouse gases (GHG) may impose restrictions on intensive livestock systems (Alderson, 2008), and increasing emphasis on agri-environment projects and non-intensive systems of production will require revised evaluations of breed suitability. It is likely to favour the natural adaptation of local native breeds. The value of these breeds will be enhanced by the high quality of their products, derived from their distinctive characteristics and from their local associations.

Scientific research

The characteristics of some endangered breeds may not meet commercial criteria but nevertheless are highly distinctive and render the breeds valuable in scientific research. North Ronaldsay sheep and Ossabaw pigs are typical examples.

North Ronaldsay sheep have an exclusive diet of seaweed for much of the year, and consequently have developed a physiological adaptation, particularly with regard to copper absorption. As a result they now are recognised as a unique scientific resource and valuable 'models' of this unusual adaptation to copper. They contribute to an understanding of an important class of childhood liver disease, and also to diseases such as Alzheimers and other neurodegenerative diseases where aberrant proteins are associated with dysfunctional copper metabolism (Haywood, 2001).

The ancestors of Ossabaw pigs were brought to North America five hundred years ago, and have evolved since that time as a feral breed on Ossabaw Island off the coast of Georgia. In response to the challenges of its inhospitable hot and humid environment, coupled with severe seasonal scarcity of food, the Ossabaw has developed the ability to accumulate large amounts of body fat during periods of good nutrition, so enabling it to survive seasons of deprivation. This physiological adaptation makes the pigs valuable models in research relating to non-insulin dependent diabetes in humans.

Heritage and history

Recent DNA studies of mitochondrial haplotypes and Y-chromosome variation have explored ancient links of endangered local breeds and brought a new dimension to the understanding of their origin and relationships, enhancing their relevance to livestock history and heritage value. One study traced the direct descent of some White Park cattle from ancestors which existed 10,000 years ago in the Middle East (Ludwig et al, 2013).

For most breeds interest focuses on the last two hundred years, a period during which time the Industrial Revolution brought dramatic improvements in transport, on both a national and global scale and native breeds have been exposed to the threat of substitution by imported breeds. Some breeds became widespread. Shorthorn cattle from Britain set a precedent which has been followed by other breeds such as Merino sheep from Spain, Landrace pigs from Scandinavia, and most recently Holstein dairy cows from North America. Countries of the European Union (EU) rely for most poultry, pig and dairy cattle production on highly developed international breeds. The effect can be dramatic. For example, in 2007 40% of the pig meat consumed in Europe was derived from one breed – the Large White (also known as the Yorkshire).

The inevitable result of the spread of these breeds has been a reduction in breeding numbers of most native breeds, and the extinction of many others. FAO records almost 750 extinct breeds (Scherf, 2000) although the list includes some duplication. The greatest recorded loss of breeds, types and strains has been in Europe. Almost 100 French breeds are listed as extinct, whereas neighbouring Spain appears to have fared relatively well – only twenty-six native breeds are listed as extinct, and these include five strains of the Spanish Merino listed as separate breeds. Extinction may mean not only the loss of breeds with important local or regional cultural significance, but also the elimination of valuable genetic merit as in the extinction of Galloway racing ponies and Suffolk Dun dairy cattle in Britain almost two hundred years ago.

The relevance of such breeds to local heritage and history can be seen in relic populations such as Maremmana cattle on the Tuscan littoral, the ancestral population of Merino sheep in Andalusia, and Sorbroget pigs (forerunners of the Landrace) in Denmark. Important local products acquire greater authenticity if they are derived from the appropriate local breed. Genuine Cotherstone and Single Gloucester cheese in England are processed from the milk of Northern Dairy Shorthorn and Gloucester cattle respectively, but both breeds are critically threatened. In contrast, the premium commanded by Parmigiano cheese manufactured from the milk of Italian Reggiana cattle has revived the fortunes of the breed.

NGOs dedicated to genetic conservation of FAnGR have recognised the change of emphasis in recent years, and have expanded their remit from simply 'rare' breeds to the broader concept of 'native' breeds. 'American Minor Breeds Conservancy' first changed its name to 'American Livestock Breeds Conservancy' and then to 'Livestock Conservancy', and 'Rare Breeds Canada' changed to 'Heritage Livestock Canada'. Some European countries have developed "strong public and private commitments to the maintenance of traditional breeds within agricultural landscapes, through a comprehensive regulatory and support framework. Characteristics of the European model include:

a public commitment, generally supported by the population as a whole, to retention of traditional agricultural livelihoods and landscapes, with use of subsidies, when necessary, to achieve that goal

relatively affluent consumers that retain considerable interest in, and willingness to pay for, high-value animal products

high levels of technical capacity and a willingness to apply that capacity to *in situ* maintenance and *ex situ* conservation of AnGR

perhaps most importantly, levels of food production, economic development, and government stability that minimize concerns about hunger and extreme poverty" (FAO, 2006).

Insurance

There may be some breeds which can not fulfil any of the preceding criteria to justify their continued existence, but the future is unpredictable and ideally all genetic resources should be conserved as an insurance against changing requirements and market demand. Many of the currently dominant breeds were 'rare' breeds in earlier times, and their qualities would not be available now if they had not been conserved when they were endangered. While this philosophy is not accepted by some pragmatists, it is increasingly understood in some sectors of the scientific community, although prioritisation is inevitable in the context of limited resources.

The significance of extinction is appreciated fully by FAO, and a report to the 4th session of the Intergovernmental Technical Working Group for Animal Genetic Resources (ITWG-AnGR:4) stated "- - it is evident that as production systems and livelihood strategies change, some breeds - - will be abandoned by farmers. If a breed or population becomes extinct, this means the loss of its unique adaptive attributes, which are often under the control of many interacting genes, and are the results of complex interactions between the genotype and the environment." (FAO, 2006).

Conservation of plant and animal variation is necessary to meet future agricultural challenges, as well as to preserve the rich cultural heritage of the various regions of the world.

METHODOLOGY OF THE CONSERVATION OF ANIMAL GENETIC RESOURCES

Prioritisation

If it is accepted that available resources are insufficient to prevent some loss of genetic variation, then prioritisation is necessary. Again, there are opposing views. One opinion prioritises the most endangered breeds; another opinion would prioritise breeds which deliver the greatest genetic diversity; while a third opinion would restrict conservation to breeds which can demonstrate commercial value - or the likelihood of commercial value. The latter option depends on an unrealistic ability to predict the future, and is contrary to FAO's warning of the dangers of breed extinction (FAO, 2006). Therefore diversity and degree of endangerment should be the basis for prioritisation.

RBI convened a meeting of governmental representatives and NGO officials in London in 2010 to define the three factors that determine a 'breed at risk', namely population size, population distribution, and population genetic structure. The outcome was adopted and formalised in 2012 in 'FAO Guidelines for the *In Vivo* Conservation of Animal Genetic Resources' which is used by national governments to categorise breeds in the SoWAnGR programme.

Population size

Prior to 2010 numerical criteria established by different organisations to define categories of endangerment lack consistency. FAO used criteria of 100 and 1000 breeding females to define critical and endangered breeds respectively. RBI proposed 2000 for species with a high reproductive rate and 6000 for those with a low reproductive rate, while the range used by the EU was 4000 to 22,500 breeding females **(Table I)**. Such extreme differences were a cause of confusion and lead to conflicting policies until they were resolved at the RBI meeting in London.

Table I. Number of breeding females which define a 'breed at risk' in 5 species (Número de hembras reproductoras que definen una "raza en peligro" en 5 especies).

Species	Equine	Bovine	Ovine	Porcine	Avian
EU/EAAP	4000	7500	10000	15000	22500
RBI	6000	6000	6000	2000	2000

Historically, for the purpose of prioritisation, most organisations have measured population size as the number of breeding females, but alternatives may be more relevant. Effective population size has been advocated, but it requires regular and accurate census of the population, which has not proved possible in many countries. An extension of this is probability of extinction, which is associated with expected increase in levels of inbreeding and is equally difficult to measure. The annual number of female registrations, or a three-year rolling average, is the best measure of replacement rate and therefore of the viability of a breed.

Population distribution

The distinctive characteristics of breeds are conserved most effectively when they are kept in their original habitat and exposed to the conditions under which they evolved. Many endangered breeds remain in their locality of origin and retain their natural adaptation to their environment. Unfortunately this renders them vulnerable to disease epidemics, and the concentration of a breed in one locality could lead to its extinction. Currently disease presents a greater threat of extinction than loss of genetic/environment interaction. The losses experienced by many numerically endangered breeds in Britain during the outbreak of foot-and-mouth disease (FMD) in 2001 were reduced because breeding units had been more widely distributed during the previous thirty years. On the other hand some breeds with a larger population concentrated in a small area lost up to 50% of their population.

The development of geodemographic techniques has enabled the distribution of a breed to be described by concentric circles around its weighted mean centre, where each circle encompasses a defined portion of the breed (e.g. the critical nucleus, threshold to define a 'breed at risk' which is 75% of the population). This technique is a valuable tool in the formulation of conservation policy and directing emergency action in the event of a disease epidemic.

Population genetic structure

Most endangered breeds demonstrate distinctiveness as measured by genetic distance from other breeds. It is partly a function of small population size and associated inbreeding (i.e. loss of heterozygosity). Distinctiveness has a value, and is used by FAO as an important criterion to determine prioritisation. On the other hand it presents the danger of lack of genetic variation within a breed. It is possible that the problem of inbreeding has been over-emphasised; concurrent linebreeding and selection for functional efficiency is a recommended policy to combine breed improvement with the elimination of deleterious mutations. Studies of Hungarian Grey cattle (Bodo, 1990) and Suffolk Punch heavy horses (Crew, 1999) suggest that increased inbreeding is not necessarily associated with loss of heterozygosity, while other inbred breeds (e.g. Traditional Hereford and White Park cattle) exhibit genetic erosion but no problems associated with inbreeding depression.

FAO addressed the inherent problems in the molecular assessment of Domestic Animal Diversity (DAD): "Methods to combine information on genetic relationships across studies have proven elusive, suggesting that there is need for a single, coordinated effort to identify genetic relationships among global livestock breeds. - - An emerging literature has demonstrated that measures of molecular genetic diversity (indicative of evolutionary relationships) can be combined with measures of phenotypic diversity (indicative of underlying functional genetic variation) and knowledge of geographic distribution and selection history, to provide objective guidelines for setting conservation priorities. Such an approach would greatly facilitate the targeting of international funds to areas of greatest benefit." (FAO, 2006). The concept is admirable, but the realisation more difficult.

Distinctiveness is the key factor. It is not identified solely by between-breed molecular genetic diversity, but may arise also from morphological and performance factors. However, if a breed experiences introgression its distinctiveness will be compromised and its type and function will be changed. Many British beef breeds (including the Beef Shorthorn, British White, Lincoln Red and Sussex) responded to market demands of the late twentieth century by introducing crosses of breeds from continental Europe such as Limousin, Maine-Anjou and Salers. The character of other breeds (Hereford and Aberdeen Angus) was changed by importation of breeding stock from North America. All have changed in type, their genome has been disturbed, and their founder alleles eroded. Similarly, crossing with Duroc pigs compromised the genetic integrity of British Saddleback and Tamworth pigs in Britain and threatened the unique quality of speciality processed ham in Spain derived from the genetic/environment interaction of Iberic pigs in the dehesa.

Although introgression, whether by official grading-up programme or by illicit crossing, compromises distinctiveness, it may be justified in extreme cases. The Chato Murciano pig, which declined to a very small population of 24 breeding animals with high levels of inbreeding, was revived by a planned programme of crossing with the Large White. Similarly, the Norfolk Horn sheep breed in England was re-established by back-crossing the remnant population with the closely related Suffolk. Both recovery programmes were justified, but the resulting breeds will never be true representatives of the original breed.

MAINTAIN GENETIC INTEGRITY

The conclusion reached in an overview of animal genetic resources is that the primary focus in the conservation of domestic animal diversity is the conservation of breeds, as "each breed comprises a unique set of genes" (Barker, 1999). The genetic integrity of a breed is built on established interactions between genes in its genome, and the introduction of exotic genes disturbs the patterns of interaction. Thus the concept of breed purity, established by founders of Stud/Herd/Flock Books, can be reinforced by DNA technology. Previously the ancestry of an animal was determined by historical records, or occasionally by anecdotal evidence. Now it can be confirmed by DNA testing, which has identified significant inaccuracies in the registration records of several breeds.

Registration data previously has provided evidence of recorded introgression, but the development of DNA technology has provided an incisive tool to analyse the profile of each breed, and this acts as a template against which the profile of any individual animal can be measured. For example, it is possible to demonstrate among French dairy breeds that the Montbeliarde and Abondance have retained a greater degree of their genetic integrity with only circa 5% North American Holstein introgression (Mattalia et al, 2006), much less than many other European dairy breeds which have accepted a high level of Holstein introgression.

Breed assignment systems based on allelic frequencies and exotic alleles have been applied to several uses including parentage verification and the authentication of products in relation to the donor animal. A system used as part of the registration procedure for White Park cattle in the UK requires a DNA test for all bulls, together with a DNA test for both sire and dam of each bull. This permits not only parental verification, but also has established a breed profile which is utilised for breed assignment procedures. Similar systems operate for equine, porcine and ovine breeds, and have detected Duroc introgression in both British Saddleback and Tamworth breeds.

Despite its undoubted value, DNA profiling raises other questions. If an animal has an untypical DNA profile for its breed, should it have high priority as a source of genetic diversity, or is it an indication of introgression? Therefore there remains a need for other measures of evaluation (e.g. historical records, morphology, function, anecdotal) to complement DNA data.

Maximise diversity

Current genetic conservation theory seeks to maximise diversity, and much debate revolves around the relative merits and application of within-breed and between-breed diversity. The argument was explored in the PigBioDiv1 European project, and methods of combining the measures were proposed, but generally it has been accepted that between-breed diversity is the major criterion to be taken into account when setting priorities for conservation. This leads to the concept of 'marginal diversity' and demonstrates that local breeds contribute 55.9% of the total genetic diversity found in European pig breeds (Ollivier et al, 2005). PigBioDiv1 inspired further research projects with local breeds, especially in Europe (Bozzi et al, 2018).

A contrary opinion proposes the use of marker estimated kinships (MEK) as a measure of diversity (Eding, 2002). It argues that use of genetic distance (i.e. between-breed variation) favours the conservation of inbred populations, and that the loss of small populations which have experienced accelerated genetic erosion leads to only a minimal loss of overall diversity. This opinion would be prepared to accept the extinction of many local breeds, and therefore fails to recognise either the relevance of established gene interactions within each breed genome, or the distinctive functions of local breeds. The conflict of opinion is demonstrated by minority native pig breeds in the UK. Breeds with the greatest heterozygosity (observed) showed the lowest marginal between-breed diversity **(Table II)**. In this evaluation, heterozygosity was associated closely with introgression (e.g. British Lop and Saddleback), and analysis of 'private' alleles within the British group of breeds gave some indication of the likely source of introgression (e.g. Duroc).

Threats to diversity come from many sources. Intensive selection is a major culprit affecting within-breed diversity. It may be targeted at breed improvement, and is particularly dangerous when focused on a major gene. It may be used for disease control, as with the elimination of scrapie-susceptible genotypes in sheep. The heavy use of 'fashionable' animals, often prize-winners in the showring, also causes genetic erosion. Between-breed diversity is reduced by introgression of exotic genes, and by breed substitution. The latter is particularly important in the developing world where 'dumping' by developed countries of obsolete genetic material in 'aid packages' results in the marginalisation of locally adapted breeds in Africa.

A careful evaluation of the genetic diversity of each species is required before setting the most appropriate conservation strategy, and an increasing array of tools is available. DNA profiling provides evidence of diversity from allelic frequencies, and it can be used in conjunction with calculations of effective founder number (GCI) and inbreeding. A recommended two-step procedure is:

Identify and prioritise breeds with the greatest marginal diversity and vulnerability, combining measures of between-breed diversity and probability of extinction

Develop breeding programmes, based on analyses of breed structure, to maximise within-breed diversity in those breeds.

Maximise founder genome

Early genetic conservation programmes focused primarily on restriction of inbreeding as the favoured method of maximising heterozygosity, but the use of inbreeding coefficients in isolation can be a misleading measure of genetic variability, and effective founder number (GCI) is a more relevant measure in a breed or population (Alderson, 1992). GCI is the number of founders with equal contribution that would produce the same genetic variability as exists in the breed. Ideally the influence of each founder is transmitted through several progeny at each generation, but most populations experience a genetic 'bottleneck' at some time in their history. Calculation of the effective ancestor number, used in conjunction with GCI, can overcome this problem. A further measure, founder genome equivalent, which measures the retention of founder alleles and their frequency at each locus, has been proposed (Lacy, 1989) to account for genetic drift as a cause of loss of genetic variability.

Table II. Measures of microsatellite diversity in seven pig breeds at 24 loci (Medidas de diversidad de microsatélites en siete razas porcinas en 24 loci).

Breed	MB^	Ho	Alleles p locus	Homozygous loci	'Private' alleles*
Tamworth	5.33	0.461	3.25	0	5
G.O.S.	4.72	0.432	3.13	3	3
Berkshire	4.55	0.463	3.30	3	6
Middle White	4.06	0.486	3.83	2	7
Large Black	3.96	0.506	4.29	1	9
British Lop	3.12	0.563	4.26	0	11
Saddleback	1.71	0.555	6.00	1	20

^ Marginal between-breed diversity (Ollivier et al, 2005).
* Within this group of British breeds.

A Norwegian study (Olsen, 2005) applied various measures (effective number of founders, effective number of ancestors and effective number of founder genomes) to the analysis of two native horse breeds and concluded that the "- - use of probabilities of gene origin is more robust - -" than inbreeding coefficients as a measure of genetic variation in a population.

Effective population size has value as an indicator of the likely increase in homozygosity, but is subject to the influence of several factors. Rare breeds, such as Braque Saint-Germain (French pointing dog) (Leroy et al, 2006) or Nordland horses (Olsen, 2005), inevitably have a low effective population size, but some mainstream breeds are not immune from the problem and their narrow genetic base is reflected in a low effective number of ancestors **(Table III)**. A study of the ubiquitous Holstein dairy cow in France revealed an effective population size of only circa 50 (Boichard, 1996), and the equally numerous Thoroughbred racehorse is even lower at a level comparable to some numerically endangered breeds.

Minimise inbreeding

The EU, after advice from the Animal Genetic Resources committee of EAAP, has taken 'probability of extinction' as the basic criterion for prioritisation, and based critical population size of a breed on the expected increase in homozygosity in a period of 50 years **(Table I)**. This reduces the evaluation of endangerment to a mea-

Table III. Measures of genetic diversity for 3 breeds (Medidas de diversidad genética para 3 razas).

Breed	Braque Saint-Germain dog	Nordland horse	Holstein dairy cow
Effective population size	40	62	50
Effective number of ancestors	13	7	22

Table IV. Measures of genetic diversity for 5 breeds
(Medidas de diversidad genética para 5 razas).

Breed	Vaynol	W.P.	Shetland	TB	Holstein
GCI	6.87	13.03	31.47	28.15	n/a
No. of founders to contribute 50% of genes	3	5	11	12	n/a
Contribution of most important ancestor	0.24	0.27	0.13	0.14	0.13
Inbreeding average (%)	16.0	12.5	n/a	n/a	5.1

surement of generation interval of the species, and is too simplistic and theoretical. In practice, systems of breeding applied to endangered breeds differ from those used for mainstream livestock. The mating ratio is smaller, and the maintenance of 'unfashionable' lines is positively encouraged. Thus a functional measurement of endangerment includes not only generation interval, but also mating ratio and reproductive rate. In theory, a high reproductive rate makes a breed vulnerable to rapidly increasing homozygosity; in practice, it gives greater opportunity for survival.

All breeds are vulnerable to loss of genetic variation. Numerically small breeds are subject to genetic drift, while intensive selection programmes are applied to most popular breeds. Consequently, a mainstream breed may be threatened as much as a 'rare' breed. Comparisons of two breeds with large populations (French Holstein dairy cattle and Thoroughbred racehorse) with two breeds at risk (White Park and Shetland cattle) and a critically endangered breed (Vaynol cattle) reveal surprisingly small differences. For example, the results for Shetland cattle (700 breeding cows) are very similar to those for the internationally popular Thoroughbred **(Table IV)**, and the French Holstein (c.3 million cows) has comparable results (Mattalia et al, 2006). The Holstein results confirm earlier breed analyses from the USA (Young & Seykora, 1996).

Control of inbreeding is achieved most effectively by a system of cyclic crossing whereby a population is divided into groups of related animals (Alderson 1981). Within each group a nucleus of females is mated to males of the same group (linebreeding) while the remainder are mated to males of the adjacent group in the cycle, and this procedure is repeated each generation. It involves a degree of inbreeding to maintain the distinctiveness of each group, but maximises the overall diversity of the population. This system has been applied effectively with several breeds, including Portland sheep and Caspian horses.

Conserve in original environment

The emphasis by FAO, RBI and other relevant bodies on the importance of native breeds, is consistent with the conservation of AnGR in their original environment, and this should be the prime objective. In some cases it has not been possible. Dexter cattle were extinct in their country of origin (Republic of Ireland) for much of the twentieth century, but were maintained in North America, South Africa, Australasia and Britain. Wessex pigs became extinct in England after their amalgamation with the Essex in 1967, but continue to be conserved in Australia. In these cases, foreign populations can play an important role in the survival of a breed.

Therefore, *in situ* conservation should receive priority, and *ex situ* (both *in vivo* museum populations and cryogenic stores) should act as supporting subsidiary mechanisms. The special genome of each breed has evolved in response to its native environment to give it local adaptation. This is illustrated clearly by mountain breeds of sheep in Britain, such as Rough Fell on Silurian shales and Herdwick in the Cumbrian Lake District. For some other breeds it has limited relevance. Those which are managed mainly in intensive (artificial) systems, both indoors and outdoors, are not adapted to the conditions of any particular locality.

"- - a global view of patterns of change in AnGR use reveals both the continuing need for highly adapted local breeds in more slowly evolving production systems and in marginal ecological conditions, and increasing recognition of the importance of conserving local breeds." (FAO, 2006)

Characterisation

The effective use of native breeds, and the potential value of cryogenic archives, requires characterisation of breeds and donor animals, and this falls into four main categories, namely biochemical, morphological, functional and behavioural.

Biochemical

The value of DNA analysis has been realised in practice in various ways such as work on porcine colour genes and screening of colour polymorphisms in Berkshire pigs for export to Japan (Alderson & Plastow, 2004), in assignment to breed and in parentage verification. FAO has published panels of recommended loci for DNA analyses, and advised the number of animals and loci appropriate to compile a breed profile but, in view of the introgression suffered by many breeds, insufficient attention is paid to sampling procedure. It is essential to know for every research project the precise type of the animals involved, to know whether a sample is purebred Dairy Shorthorn rather than crossbred Blended Red-and-White, Traditional Hereford or 'modern' Hereford, Marwari or Kathiawari.

Morphological

Breeds of all species differ in type and size, and this may be a result of either selection for 'fashionable' type or response to environmental and functional influences. Some definition is possible from descriptions provided by breed societies, but often this is subjective or anecdotal. Linear assessment gives precise definition of type (Alderson, 1999) being used by the White Park Cattle Society to predict mature characteristics from measurements of young bulls, and also has been applied to other breeds such as Araucano horses in Colombia (Salamanca et al, 2017).

Functional

Function, and associated performance, also shows great variation between breeds. There was increasing specialisation of function in breeds during the twentieth century, perhaps reaching its extreme in Holstein dairy cattle and Beltex sheep. There also is variation between breeds in the level of production, ranging in British sheep from small low-performance primitive breeds at one extreme to British Milksheep at the highest level (Mitchell, 1997).

However, efficiency of production is now superseding total production as the preferred measure of productivity, and a Scottish primitive breed (Hebridean) has been shown to achieve greater productivity than the most popular commercial ewe (Mule) in terms of weight of lamb weaned per kg metabolic weight of the ewe.

Behavioural

Characteristics such as temperament, grazing preferences and homing instinct are well-recognised and valuable behavioural traits. Others, such as hardiness and thriftiness, determine the suitability of a breed for different systems of production. Some of these qualities have been fixed mainly as a result of natural selection, and are expressed as components of local adaptation. They are not defined easily by precise measurement and hence an owner's skill in animal breeding remains an essential element of breed improvement.

Utilisation

FAO places strong emphasis on the use (or potential use) of native breeds. "Conservation could take a variety of forms, including - - use of traditional breeds to produce high-value specialty foods and other animal products, maintain traditional landscapes, and support tourism - -. In the developed world, conservation of AnGR - - involves use of local breeds in both traditional roles (e.g. to produce high-value typical national or regional products for sale in various niche markets) and innovative uses (e.g., landscape management, weed control, heritage value)". Thus Dales Ponies and Suffolk Punch horses are used for forestry work where access for machinery is difficult, and local sheep breeds in Andalucia are used to maintain fire-breaks in forested areas (Barba et al, 2016). Iberian pigs, in traditional oak-forest (dehesa) production environments in Spain, produce high-value cured ham products, while in many parts of northern and eastern Europe grazing livestock has been recognized as critical in the maintenance of wildlife and native plant biodiversity in many high-value nature ecosystems.

"In the rapidly developing countries of South and Southeast Asia, local chicken breeds have long been preferred, because of their distinctive flavour, but their limited suitability for intensive production led to their rapid replacement with industrial lines. More recently, however, premium markets favouring local birds and their crosses have appeared, reflecting increases in consumers' disposable income and providing motivation for continued use. Markets such as this can appear only after an initial period of economic development, and the future value for local breeds in such markets provides justification for their conservation." (FAO, 2006).

Develop added-value markets

"Eat them to save them" was a slogan devised by the author when he launched the remarkably successful 'Traditional Breeds Meat Marketing Scheme' in 1994. A profitable outlet is the surest method to achieve effective conservation of a breed. Since the scheme began the numerical status of rare breeds in Britain has increased, particularly pig breeds.

The added-value market relies on consumer perception of several factors, including product quality, animal welfare and environment enhancement. Consumer confidence in the provenance of traditional breed products was notable during the BSE crisis in Britain in the 1990s when demand for beef in supermarkets dropped by almost 70%, but sales of beef from traditional breeds increased. The dangers posed by multinational breeding companies and supermarkets are significant, but clearly there is a strong niche market for speciality products.

Traditional products can be enhanced by PDO (Protected Designation of Origin) and PGI (Protected Geographical Indication) designations, and local breeds by a TSG (Traditional Speciality Guaranteed) brand which recognises their special and distinctive character. Parmigiano Reggiano cheese (PDO) is manufactured from the milk of rare Reggiana cattle. Products from local breeds are attractive because they are associated with low 'food miles', positive genetic/environment interaction from non-intensive production, support for local culture and local infrastructure.

Conservation grazing

The change in emphasis within the EU to agri-environmental schemes permits the exploitation of local adaptation exhibited by many native breeds in conservation grazing projects. In some cases, such as the Iberic pig in the dehesa, these are part of an established ecological pattern, but in other cases they are motivated by environmental maintenance or enhancement and take advantage of the characteristics of native breeds. Thus British pig breeds are suited to non-intensive outdoor systems, and native breeds of other species are used on heathland, wetlands and woodland.

Differences in grazing behaviour find specific application in conservation grazing. Breeds such as Hebridean sheep and White Park cattle preferentially graze coarse herbage. On moorland pasture Hebrideans grazed purple moor grass (*Molinia caerulea*), while Swaledales preferred heather (*Erica* and *Calluna*). White Parks running in a herd with Blonde d'Aquitaine cattle grazed rougher herbage at field margins, while the latter selected rich cultivated grass, demonstrating the value of native adaptation.

Conservation grazing provides an excellent opportunity for holistic conservation by ensuring that native animal genetic resources are used as an integral ingredient of the maintenance of natural biodiversity. For example, it is regrettable that a recently re-created exotic breed (Konik Pony) was used on wetland sites in England when suitable native breeds were available.

Non-commercial criteria

Current economic value is an obvious reason for the conservation of an endangered breed, but other traits also should be considered, including current scientific interest, ecological or landscape function, cultural relevance and genetic uniqueness (Ruane, 2000).

Danger of selection to meet market demands

The identification of profitable outlets for a product inevitably leads to selection of breeding animals to improve further their performance and profitability, and this in turn is likely to lead to genetic erosion.

In recent decades widespread use of techniques which can increase intensity of selection, such as BLUP, artificial insemination, embryo transfer, QTLs and genetic markers, has accelerated the loss of genetic diversity. A high priority should be placed on selection programmes which simultaneously manage rates of genetic gain and limit loss of diversity. They provide a valuable tool in the conservation of rare breeds by enabling them to exploit the benefit of their special qualities without the risk of entering a genetic cul de sac.

Ex situ preservation

Cryopreservation

Cryopreservation of gametes and embryos in national gene banks is used in several countries as a support for *in situ* conservation. Cryogenic storage not only is a safeguard against extinction of a breed, but also can be used as a tool to maintain genetic diversity.

Disease epidemics, such as foot-and-mouth (FMD) and avian influenza (AI), have become a greater threat in recent years and cryogenic stores provide a secure reservoir of genetic material. However, the primary safeguard against disease epidemics is the dispersal of a breed over a wide geographic range, even though some animals will be maintained in an untypical habitat. A more routine use of semen banks is to replenish the genetic diversity of breeds by reintroducing to breeding programmes animals from earlier generations.

Most stores combine both functions. France (Avon, 2006) and England both have large archives of bovine semen comprising allocations for both long-term storage and current use. In contrast, the Ovine Semen Archive established in response to the National Scrapie Plan, and the RBST National Archive in response to the FMD 2001 outbreak, were intended simply as an insurance against the loss of either specific genotypes or whole breeds.

Ex situ in vivo

"The primary advantage of *ex situ in vivo* programmes to conserve breeds that are no longer used *in situ* is that the animals remain accessible for study and potential future use. Given the relative difficulties of high cost and the number of years /generations required for restoring a livestock breed from material stored in gene banks, the decision not to maintain live animals of an endangered breed is likely to limit the future restoration of the breed to conditions of extreme need, and preclude most speculative and entrepreneurial uses." (FAO, 2006)

Livestock museums, including farm parks and heritage centres, have played an important role in some countries to ensure the survival of native breeds. For example, state parks were established in Hungary in the early 1960s to maintain significant breeding units of breeds such as Grey Steppe cattle and twisted-horn Racka sheep on the puszta of Hortobagy, Lipizzaner horses in the northern hills and curly-coated Mangalitsa pigs. In Ireland, heritage centres such as Craggaunowen in Clare and Wexford Heritage Park kept rare breeds, while a network of Approved Conservation Centres in England in the mid-1970s not only provided a home for rare breeds but also an opportunity to raise public awareness about genetic conservation.

Conclusions

The principles of conservation of animal genetic resources include all breeds of livestock, but finite resources require their application to be prioritised. Endangered native breeds deserve the highest priority, not only because they contribute a high proportion of genetic diversity in the livestock population, but also because of their natural local adaptation and ability to yield speciality products of high quality. They are vulnerable to accelerated genetic erosion, and benefit from controlled programmes of support to maintain the individual genome and maximise genetic diversity of each breed.

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