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# COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

## Thematic Studies for the preparation of the first *Report on the State of the World's Animal Genetic Resources for Food and Agriculture*

## ENVIRONMENTAL EFFECTS ON ANIMAL GENETIC RESOURCES
**by**

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The significance of environmental effects on AnGR is manifold. However, our understanding of these effects is only partial. A review of these effects was commissioned by the FAO to seek out, evaluate and synthesise the evidence available on a spectrum of environment factors, biophysical and socio-economic, and their effects on AnGR at the individual animal level and the breeding population level. This document is a summary of that review. The review is published in the DAD-IS library.

Although some breeds may be well adapted to their local environment (largely bio-physical factors), the wider environment (socio-economic and agroecological factors) can not be adapted to. The negative effects of the wider environment have to be recognized and understood in the first instance, and then mediated or mitigated in order for AnGR to be conserved and managed.

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# ENVIRONMENTAL EFFECTS ON ANIMAL GENETIC RESOURCES

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# 1. Summary

The review identifies the significant genotype-environment interactions that have been found to exist in animal performance when different genotypes are compared across environments. Consideration is given to the implications of different types of genotype-environment interactions for animal genetic resources (AnGR) management. It is also shown that although some breeds may be well adapted to their local environment (largely bio-physical factors), the wider environment (socio-economic and agroecological factors) cannot be adapted to. The negative effects of the wider environment have to be mediated or mitigated in order for AnGR to be conserved and managed.

An evaluation and synthesis of evidence available on a spectrum of environment determinants, biophysical and socio-economic, and their effects on AnGR at the individual animal level and the breeding population level are presented. Implications of the environmental effects on AnGR at these two levels are discussed in terms of technical and policy issues. Knowledge gaps and researchable questions are identified.

The important components of the phenotypic expression by animals of genotype across environments are environmental sensitivity (related to phenotypic plasticity and adaptability), genotype-environment interactions and the effectiveness of selection across environments. Individual animals vary in their responses to local environmental effects. Here variability can be explained by the breed, or breeding population, of which the individual is part.

Analogous to the differential impact of the local environment on individual animals, breeding populations also vary in their susceptibility to wider environmental effects. It is notable that certain regions of the world have far greater rates of genetic erosion in AnGR than others. Important aspects to consider in the evaluation of environmental effects on AnGR erosion are the genetic variability and uniqueness of populations and the 'option' values of the AnGR. A measure of importance of these wider environmental effects is their impact on the structure and sustainability of the breeding population.

The evidence available of environmental effects on AnGR generally comes from three sources. Firstly, there are the results of experiments done under controlled conditions and designed to measure the response by individual animals to specific changes in their local environment including dietary intake, ambient conditions, disease challenge etc. Although inferences have been made about breed differences from the results of such research their validity is often compromised by the lack of a representative sample.

Secondly, empirical animal production data has been analysed to evaluate the environmental and genetic effects on different traits. Although the conditions of the local environment are not controlled valid comparisons between animal and between genotype groups can be made taking advantage of large sample sizes (numbers of animals, time over which data is accumulated) and sophisticated statistical analysis procedures. As in the case of evidence from experimental sources, the main objective is to analyse the response variable recorded on individual animals, rather than to analyse the causes and effects linkages. Indeed, often environmental effects are aggregated in the analysis and identification of the different effects of components of the local environment is not attempted (e.g. effects of herd, year and season are treated together).

The third set of evidence is from studies of the way breeding populations have responded to changes in the wider environment. These changes include those in socio-economic and agro-ecological determinants. Such studies recognise the importance of livestock keepers breeding decisions in mitigating the wider environmental effects. The focus of interest includes the

sequence and combination of environmental effects, not just the AnGR response variables. For the sustainable management of AnGR it is important to identify and analyse the ways breeding populations (and the breeding decisions livestock keepers make) react to socio-economic and agroecological changes.

## 2. Introduction

The significance of environmental effects on animal genetic resources (AnGR) is manifold. However, our understanding of these effects is only partial. A better understanding of environmental effects is required if AnGR are to be managed sustainably.

This document presents a summary of the evidence available on a spectrum of environment factors - biophysical[1] and socio-economic, and the ways they effect AnGR at the individual animal level and the breeding population level.

It is recognised that livestock keepers mediate many environmental effects through their breeding and husbandry decisions, and hence, the factors that influence these decisions are crucially important to understand. One of the most important set of factors affecting livestock keeper decisions is the policy framework.

## 3. When are environmental effects on AnGR important?

### *3.a. Individual animal level*

What can be observed of an animal – its phenotype – is the product of the expression of its genotype mediated by the local environment. Changes in the local environment, or if the genotype is moved to a different environment, will result in another set of environmental effects. Environmental effects are important when they alter the expression of the genotype sufficiently for the phenotype to change.

The adaptive value or fitness of a genotype can be appreciated when its performance for a trait is measured under different conditions. Assertions that animals should be selected for productive traits under favourable environments whereby the genotype's "potential" can be expressed, and that animals thus selected will be superior to animals bred in unfavourable environments, have shown to be misconceived. Evidence for this is provided by measurements of within and between genotype performance over environments and various experiences of importing so called 'improved' genotypes into unfavourable environments.

As livestock production systems are being required to internalise the costs of their environmental impact and consumers are becoming more interested in the agroecological and welfare aspects of animal production, breeders have recognised the need to develop genotypes with combinations of productive and adaptive characteristics. This, in conjunction with previous selection programmes that significantly narrowed the genetic base of populations, means that an inflow of genotypes has and will take place from less intensively managed populations kept under less favourable environments. Aspects that are important to evaluate in this respect are the genetic basis for adaptive traits and the importance of genotype-environments interactions.

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[1] Biophysical effects can be divided into two categories, short-term, including droughts, cold, floods, human caused disasters, earthquakes, disease outbreaks; and long-term ecological events, including, climate change and agroecological changes.

### *3.b. The breeding population level*

Analogous to the differential impact of the local environment on individual animals, breeding populations also vary in their susceptibility to environmental effects. It is notable that certain regions of the world have far greater rates of genetic erosion in AnGR than others. Important aspects to consider in the evaluation of environmental effects on AnGR erosion are the genetic variability and uniqueness of populations, and the option values of the AnGR related to the adaptive traits segregating in the breeding populations. A measure of importance of these wider environmental effects is their impact on the structure and sustainability of the breeding population.

## 4. Environmental effects and AnGR management

To the simple concept of the animal's phenotype being an expression of its genotype mediated by the environment, we have to add that genotypes vary in their capacity to adapt to different environments and that the effect of the same environment will vary across genotypes.

The way that animals respond to environmental effects is related to the adaptation of the animal and breed. Animals express differing levels of short-term adaptability when they are challenged with new environmental factors. Favourable mutations enable adaptation across generations to environmental effects. Such adaptation (sometimes referred to as "adaptive value" or "fitness") is a genetic response to directional local environmental influences. Genetic variation within AnGR is made use of by livestock keepers that recognise the advantageous effects of natural selection and apply breeding decisions to procure and maintain AnGR that fulfil demands for a portfolio of goods and services from breeds of animals. Such variation is recognised and managed at the between species, across breeds and among individual animal levels.

The projected shift of animal production to industrial based systems provides important challenges for gene conservation. The "maintenance of variation among lines and breeds through diversification in breeding goals … remains justified to serve various markets and environments and to deal with risk"[2]. The international community is beginning to recognise the contribution of AnGR to sustainable agriculture and the importance of maintaining genotypes that fulfil all the different needs of humankind.

There is concern about the erosion of AnGR firstly, because current use of breeds may not be rational or optimal. Secondly, because future options, in terms of genetic traits, may be disappearing. Current use of AnGR may not be rational due to information deficits (livestock keepers and other AnGR managers not having sufficient knowledge of AnGR available elsewhere). In addition, possible external costs and benefits of AnGR used and not used may not be reflected in market values. Market failures have been identified as important causes of genetic erosion in AnGR[3].

Factors that threaten animal genetic resources and cause genetic erosion of AnGR include[4]:

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[2] Brascamp, E. W., A. F. Groen, I.J.M. de Boer and H. Udo, 1998. The effect of environmental factors on breeding goals. Proceedings of the World Conference on Genetics Applied to Livestock Production, p. 129–135, January 1998, Armidale, Australia.

[3] Drucker, A., Gomez, V. and Anderson, S. (2001) "The economic valuation of farm animal genetic resources: a survey of available methods" Ecological Economics 36/1 pp: 1-18 ISSN: 0921-8009 http://www.elsevier.nl/cas/tree/store/ecolec/sub/2001/36/1/1163.pdf

[4] Rege, J. E.O., and Gibson, J. P. (2003) Animal genetic resources and economic development: issues in relation to economic valuation. *Ecological Economics*, Vol **45**, pp 319-330.

- crossbreeding with and/ or replacement by, exotic breeds in programmes designed to improve animal productivity (many such programmes fail to increase productivity as exotic germplasm is not appropriate to some production systems);
- neglect arising from shifts in social settings, production systems and/or market demand of certain animal products;
- urbanisation and its impact on traditional animal agriculture;
- drought;
- civil strife/conflicts;
- and famines.

All these factors are part of the environment and context of AnGR management. Environmental effects have differential impacts across individuals and breeds. Individuals and breeds vary both in their value to humankind (for direct, indirect and option use, and bequest and existence values), and their population status (a determinant of susceptibility to environmental effects including management decisions). Irreversible loss of genetic diversity reduces opportunities to improve food security, reduce poverty and shift towards sustainable agricultural practices. The challenge confronting the managers of global AnGR is to develop approaches that allow economic development to occur while maintaining and utilising genetic diversity.

Breeding goals and conservation objectives need to consider not only the economics of the market but also the wider socio-economic, cultural and ecological environment. Hence, a more complete understanding of the effects of environmental determinants on AnGR is required in order to manage better the portfolio of farm animal species, breeds and individuals.

## 5. Evidence of environmental effects on AnGR

The evidence available for environmental effects on AnGR can be divided into three types:

- Firstly, there are reports in the scientific literature of experiments that investigate the ways groups of animals of different breeds and crosses respond to management regimes (variants on nutrition and/or reproductive husbandry). The response variables examined are mainly animal productive performance indicators. The relevance of this type of information to the understanding of environmental effects on AnGR is in terms of how animals respond to changes in their immediate environment;
- Secondly, the effects of genotype-environment interactions on the productive and adaptive performance of breeding populations are analysed. Livestock keepers, when deciding on which breeds to keep, may or may not take such indicative information on the adaptability of breeds into account;
- Thirdly, empirical evidence exists on the way breeding activities have helped farm animal populations to respond to environmental changes as diverse as climatic disasters and policy initiatives.

In the case of the first type of evidence (experimental evidence derived from data recorded under controlled conditions), issues of causality are straightforward and inferences are made about breed comparisons. However, such inferences are of arguable validity due to the often small number of animals involved and whether or not they can be considered representative of the breeds. For the second type of evidence (genotype-environment interactions in production systems), advances in statistical modelling have allowed precise estimates of genetic variation to be made across different environments. In the case of empirical evidence from breeding populations, the determination of causality is not straight forward as many causative factors may be involved. Response variables tend to be estimates of changes in aggregate population number.

This empirical evidence requires careful explanation and an analytical framework to guide interpretation[5].

## 6. Environmental effects at the animal level

### *6.a. Adaptation & plasticity*

Central to an understanding of how environmental effects interact with genotypes are the processes of adaptation and plasticity. Changes in local environments are reacted to by organisms in various ways including inter-generational genetic changes (adaptation) that affect the adaptive value or fitness of the organism. Artificial selection is also used to cause inter-generational genetic changes.

The capacity of certain genotypes to produce different phenotypes in different environments is termed 'plasticity'. When a genotype's response to changes in environmental effects is reflected in different phenotypes it can be inferred that the genetic traits involved are sensitive to environmental variation.

As animal production systems develop and management practices change so the local environments that animals are exposed to change. In addition AnGR are increasingly managed as global populations liable to be dispersed across ranges of environments. Genetic selection of AnGR needs to take this into account by including environmental differences and developments in breeding goals. Plasticity can be selected for when information on phenotypic change over environments can be collected and systematised[6]. However, the logic of selecting for 'robustness' in productive traits measured in the short-term (single lactation's, within season fertility) over a few environments is arguable. It is plausible that selection for genotypes that are adaptive as well as productive would require both plastic and robust (non-plastic) attributes.

Genetic selection for productivity under managed conditions has led to breeds and animal husbandry being de-coupled from local natural environments[7]. There is evidence that breeds selected for intensive production systems have lost adaptive traits and are therefore more susceptible to biophysical environmental effects[8],[9]. For instance, in the dairy sector there is now an increased awareness and evidence of selection for milk yield leading to undesirable genetic changes in fertility, disease incidence such as mastitis, and overall stress susceptibility.

Modeling experiments have shown that increased environmental sensitivity may indeed result from selection for high phenotypic value when there is genotype-environment interaction. Further, the results demonstrated environmental sensitivity increases with or without a

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[5] See Anderson, S. (2004) Environmental effects on Animal Genetic Resources: a review. Commissioned by AGAP FAO.

[6] Kolmodin, R., Strandberg, E., Madsen, P., Jensen, J. and Jorjani, H.(2002) Genotype by environment interaction in Nordic dairy cattle studied using reaction norms. Acta Agric. Scand. Sect. A Anim. Sci. **52**, 11–24

[7] Tisdell, C. (2003) Socioeconomic causes of loss of animal genetic diversity: analysis and assessment. *Ecological Economics*, Vol **45**, pp 365-376

[8] Sorensen, P. (1999). Interaction between breeds and environments? *Poultry as a tool in poverty eradication and promotion of gender equality*, The Landboskole, Denmark. The Danish Agricultural and Rural Development Adviser's Forum (ARDAF). 4

[9] Anderson provides a review of this evidence. Anderson, S. (2004) Environmental effects on Animal Genetic Resources: a review. Commissioned by AGAP FAO.

simultaneous improvement of conditions. This increase was greater when selection was carried out in an improving environment[10].

### *6.b. Genotype-environment interactions*

Conventionally the impact of different environments on animal genotypes is referred to as a genotype-environment interaction[11]. Such interactions are said to occur when the changes in performance of animal genotypes are not equal across different environments. Commonly this takes the form of recording the performance of a given breed, or small set of breeds, in two or more environments. Genotype-environment interaction estimates indicate the tendency for the size of performance differences between genotypes to depend on environmental effects.

Most (but not all) scientific evidence supports the assertion that the probability of genotype-environment interaction increases as the difference in prevailing conditions of the environments widens and the genetic distance between the breeds increases.

Many reports concur that genetic gain is compromised when herd production levels are restricted by the environment resulting in depressed genetic variance. However, research is still required to complete a systematic exploration of genotype-environment interaction levels across production environments for the main productivity traits of the most important species.

Biophysical environmental stress can depress growth rate primarily through the depression of food intake, but also by affecting digestion and metabolism. In stressful environments animals which are more resistant to stress therefore have higher growth rates and also lower mortalities, and are consequently more productive. Selection for growth rate under continued stress results in animals with high adaptation but low growth potential. Alternatively selection under continued low stress leads to genotypes with high growth potential but low adaptation. Confirming this, recent studies on genetics of heat tolerance in Holsteins in the southern USA indicate that selection for increased production under mild or cold climates reduces heat tolerance. In addition, the variance of heat tolerance was high indicating that there is sufficient genetic variation for successful selection for heat tolerance.

It is recognised now that genetic superiority for a trait or a combination of traits may vary across environments. Estimates can be made of the relative efficiency of indirect selection in a different environment compared to direct selection in the target environment (useful where the cost of selection in the target environment is prohibitive). Determinants are the genetic correlation and heritabilities of the trait in the two environments. The higher the genotype-environment interaction, the less effective is the indirect selection.

Evidence exists that the genetic effects important in crossbreeding may not be stable across production environments. However, few studies have specifically investigated the interaction of heterosis (hybrid vigour released by crossbreeding) with environment and of maternal or direct genetic effects with specific production environments.

## 7. Environmental effects at the breeding population level

There have been few attempts to analyse the effects of environmental determinants on aggregated levels of AnGR (considered here to include a range from individual livestock keeper's herds to entire breed populations).

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[10] Kolmodin, R., Strandberg, E., Madsen, P., Jensen, J. and Jorjani, H.(2002) Genotype by environment interaction in Nordic dairy cattle studied using reaction norms. Acta Agric. Scand. Sect. A Anim. Sci. **52**, 11–24

[11] Falconer, D. S. & McKay, T. F. C. (1996). *Introduction to quantitative genetics.* 4th ed. Longman Sci. and Tech.; Harlow, UK

The FAO LEAD initiative used a pressure-state-response model to explore the loss of animal diversity. Causes listed for the erosion of AnGR are all related to wider environmental effects. Three are prioritised:

- Destruction of the native habitats of livestock breeds;
- The development of genetically uniform livestock breeds;
- Farmer and/or consumer preferences for certain varieties and breeds (and changes in consumer preferences over time).

These causes operate in the context of:

- Policies to promote high input/output production systems (e.g. subsidies, credit, market standards);
- Livestock keepers not appropriating the genetic and ecological (and social) cost of their breeding decisions based on short term profit motivation;
- Inequitable distribution of resources and a lack of respect for (or recognition of) local knowledge and livestock management practices.

The inter-relatedness of the causes and the contextual factors identified above makes the situation complex. Hence, the causality of different environmental effects is difficult to unravel. A systematic approach has been developed for understanding this complexity[12]. Environmental effects on AnGR can be categorised into two sets. Those that act directly upon aggregated levels of AnGR, and those that act by affecting livestock keepers' breeding decisions.

### *7.a. Livestock keepers' breeding decisions*

Livestock keepers' decisions are central to both the causes of erosion and the contributory factors. Livestock keeper breeding decisions are one of the main driving forces of changes in AnGR inventories, and also a mediating factor positioned between wider environmental factors and the slate of AnGR maintained within livestock keeping systems.

Much work on farmer decision making attempts to model the economic aspects of decisions assuming economic rationality on behalf of the farmer. Such approaches may be appropriate for profit-oriented farming systems but are unlikely to be able to explain AnGR management decisions by traditional livestock keepers and those in semi-subsistence systems. For such systems approaches that reveal and investigate actual decisions are more useful.

Work that examined farmer preferences for cattle breeds in West and Central Africa[13] led to the conclusion that *ex-ante* assessment of livestock keepers' breeding strategies and breed preferences are vital for breed conservation and improvement and enable:

- assessment of current stocks and future trends in breeds held by keepers;
- research into breed attributes;
- identification of likely markets for existing or improved breeds; and,
- determine the incentives required for breed conservation.

Work in Ethiopia investigated the impact of external interference on the maintenance of the Boran cattle genetic resources. The findings show that pastoralist livestock keepers made breed and species keeping decisions in response to the deteriorating natural environment. The Borana

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[12] Anderson, S. (2004) Environmental effects on Animal Genetic Resources: a review. Commissioned by AGAP FAO.

[13] Jabbar, M. A., Swallow, B. M., d'Iteren. G. D. M. and Busari, A. A. (1998) Farmer preferences and market values of cattle breeds of West and Central Africa. Journal of Sustainable Agriculture, **12** (2/3) p.21-47

pastoralists chose to keep increasing proportions of Ayuna cattle, known to have lower demands for forage than Qorti Boran cattle. They also increased the proportion of camels in their herds.

An inter-continental historical overview of animal breeding concluded that the private sector only gets involved in AnGR development when livestock enterprises show potential for growth. Co-operative or public long-term funding is needed to develop programmes directed at smallholders. Formal sector AnGR projects have ignored the social circumstances of beneficiary groups in the setting of breeding and AnGR conservation objectives. In particular AnGR management and improvement strategies for poor livestock keepers need to address the issue of risk aversion.

Livestock keepers' decisions of which individual animals to breed and which breeds to rear are in part products of socio-economic processes and fundamental in the mediation of wider environmental effects on AnGR. Only when the utilisation of animal genetic resources is attractive at the local level, these animal genetic resources will be conserved by the private sector, the farmers, for future generations.

Despite an emerging consensus on the importance of environmental factors that operate at the aggregate levels of AnGR, little has been done to systematise the empirical evidence available. To understand the complexity of the inter-relatedness of environmental effects an analytical framework is required that complicated considers temporal aspects of the sequential impact of effects[14].

In production situations farm animals (individuals and populations) are subject to many different environmental determinants of short, medium and longer term effects. These determinants may have single point impacts, may have cyclic effects or be part of increasing or decreasing tendencies. Effects will vary in level of impact.

At the aggregated levels of a livestock keeper's animal inventory (groups of animals of different age and sex categories, breeds and species) and breed populations (the level most often used to estimate impact of genetic erosion) not only biological but also socio-economic response variables are of interest. Table 1 below sets out the genetic significance of different types of environmental effects for AnGR.

[14] See Anderson, S. (2004) Environmental effects on Animal Genetic Resources: a review. Commissioned by AGAP FAO.

**Table 1. The genetic significance of the environmental effects pathways included in the analytical framework**

| **Environmental Effects** | **Examples of determinants** | **Genetic significance** |
|---|---|---|
| Livestock keepers' decisions on AnGR inventories. | Livestock keepers' resource base, production objectives, social capital, livelihood level | AnGR mainly resides in the herds & flocks of livestock keepers. The aggregate impact of their breeding decisions is the most direct environmental effect of AnGR. |
| Changes in bio-physical determinants on AnGR inventories. | Short, medium or long term climatic effects;<br>Changes in agroecosystems etc. | Natural selection is essentially genetic change as responses to changes in local environments. Even where artificial selection is applied the impact of the local bio-physical environment can influence which animals are able to breed. In more extensive animal production systems this influence is even more significant. |
| Socio-economic determinants on livestock keepers' breeding decisions | Markets;<br>Policy interventions (incl. subsidies, tariffs, taxes);<br>Breed improvement programmes etc;<br>Ownership rights, IPRs etc. | For most livestock keepers the most important related factors that determine their breeding decisions are socio-economic.<br>The more the livestock keeping is integrated into the market the greater is the importance of these factors for breeding decisions.<br>In addition, markets failure is a significant cause of genetic erosion. |
| Changes in bio-physical determinants on livestock keepers' breeding decisions. | Short, medium or long term climatic effects;<br>Changes in agroecosystems etc. | Breeding decisions will be affected by the agro-ecological context of the animal production system. This is particularly the case in mixed farming systems where livestock provide intermediate goods & services to the agroecosystem. As the agroecosystem changes the demand for livestock goods and services also changes and this will affect the suitability of different breeds and species. |
| Socio-economic determinants on AnGR inventories. | Markets;<br>Policy interventions (incl. subsidies, tariffs, taxes);<br>Breed improvement programmes etc; | The AnGR inventories held by livestock keepers and the wider inventory available to them to include in their herd or flock is determined both by the market for AnGR and interventions by governments etc in that market. Government and donor livestock development programmes have had major influences over the availability of breeds at different times. |
| AnGR inventory on livestock keepers' breeding decisions | Population structure (Ne);<br>between and within breed genetic diversity;<br>genetic merit etc | Livestock keepers can (only) draw on available AnGR invetories to implement their breeding decisions. The availability of breeding males (or AI services) at crucial times of female cycles is crucial. The diversity of choice available to livestock keepers depends to a large extent on their acquisition ability. The quantity and accuracy of the information about the available AnGR inventory both affect decisions and the effectiveness of decisions. |
| Interactions and knock-on effects of socio-economic and biophysical determinants | Markets;<br>Policy interventions (incl. subsidies, tariffs, taxes);<br>Breed improvement programes;<br>Short, medium or long term climatic effects,<br>Changes in agroecosystems | Interactions may ameliorate or exaserpate the effects of these determinants. Knock-on effects occur when either changes in socio-economic factors cause changes in biophysical determints or vice a versa. |

### *7.b. Short and long term agro-ecological effects*

Although research on the impact of longer term climatic and agroecological effects[15] on livestock keepers' decisions and AnGR inventories is scarce, sufficient evidence exists to demonstrate how important AnGR are being lost due to changes in agro-ecological determinants (often with strong interactions with socio-economic factors – see example in Box 1 below). Such considerations are brought into sharp focus through recognition of the need to develop breeds capable of fulfilling needs for efficient animal production under conditions of negative climate change. In order to first identify and analyse, and then to rectify causes of genetic erosion in AnGR inventories of important option value, a clear understanding of the inter-relation, sequence and net effects of environmental factors is required.

**Box 1.** Disturbed resource management affects Boran cattle (Homann *et al*, no date)

The traditional land use system of Borana pastoralists was based on well-planned movements between functional range land categories and on herd splitting, to ensure availability of adequate grazing and water.

Artificial water ponds in Dida Hara region opened up the area for permanent grazing and uncontrolled settlement and thus led to reduced mobility of the herds causing overgrazing in the formerly only temporarily used pastures. At the same time, the imposition of a top down formal administration has essentially contributed to the destruction of the indigenous pasture management institutions.

The pastoralists have adjusted their breeding strategies to the deteriorated agroecology by selecting for *Ayuna*, a cattle breed with lower demands for forage than the typical Boran cattle, *Qorti,* and by increasing the proportion of camels in their herds.

### *7.c. Analysis of case studies of genetic erosion of AnGR*

The FAO commissioned a review of evidence of environmental effects on AnGR[16]. The review includes an analysis of two in-depth cases studies of genetic erosion in AnGR. The case studies provide empirical evidence to assess the importance of different causative factors including the driving forces of livestock development identified by the World Bank – increasing demand, structural changes, macro-economics institutional changes, and changing functions and systems evolution. The latter driving force was evident in both cases. The response of specialised producers and the support given by policy institutions led in different ways to reductions in the stock of local AnGR.

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[15] The world's main pasture areas, including the Argentinean pampas, the arid Sahel, the Mongolian grasslands, and the rain fed grasslands of New Zealand, have not changed in size during the past three centuries. Nevertheless, increases in pasture areas have occurred in the less densely populated regions of tropical Africa and Latin America, often at the expenses of forests. These changes were matched by declines of around 20 per cent in Europe, south Asia and North America where the shift has been to more intensive livestock production systems. However, China and Saudi Arabia in Asia, have accounted for 9 per cent rise in global pastureland over the last 25 years (Harrison and Pearce, 2000).

[16] Anderson, S. (2004) Environmental effects on Animal Genetic Resources: a review. Commissioned by AGAP FAO.

The livestock keepers' decisions in both cases were central to the causes of erosion (reacting to socio-political and agroecological determinants negative to the AnGR). However, in both cases livestock keeper breeding decisions mediated negative environmental factors and ensured the survival of a slate of local AnGR within the livestock keeping systems. The evidence is clear that assumptions of market-driven economic rationality on behalf of such farmers hinders the explanation of their AnGR management decisions.

The main lesson from the analysis of cases is the importance of socio-economic determinants. Although breeds may be considered well adapted to their local environment, the wider environment can not be adapted to. The significant genetic value of the breed populations analysed was not recognised by other than a few livestock keepers. The survival of the AnGR relies on their decision making which in one case has now attracted external support and in the other has not.

## 8. The implications of environmental effects for AnGR management and conservation

It has been shown that significant interactions have been found to exist in animal performance when different genotypes are compared across environments. In addition, evidence from the population dynamics of different breeds shows that severe genetic erosion has occurred in breeds due to socio-economic factors despite the comparative advantage of these breeds for key productive and adaptive characters. Hence, breeds although may well adapted to their local environment (largely bio-physical factors), the wider environment (socio-economic factors) cannot be adapted to. The negative effects of the wider environment have to be mediated or mitigated in order for AnGR to be conserved and managed.

# Technical and policy issues

## 9. Breeding for different animal production systems – implications of genotype-environment interactions for AnGR management

In high external input animal production systems very strong genotype-environment interaction are rare and adapted breeding goals have been used to overcome interactions where they exist. Applied breeding programmes recreate the conditions of commercial production as closely as possible for the breeding populations. In other cases sib and offspring testing under commercial conditions is used. However, as the range of environments increases within which intensive animal production systems are employed the likelihood of significant genotype-environment interactions occurring also increases. For example, the location of intensive pig and poultry enterprises in peri-urban areas in tropical environments means that productive performance is prejudiced. The significance of environment effects on intensive production systems inevitably increases as the cost of infrastructure rises due to the requirement of the producers to internalise the cost of the environmental impact of the high external input production system.

In the case of low external input systems the consequences of genotype-environment interactions have been that the many breeding operations and companies perform breeding and selection in the same environment as the animal has to produce. The alternative is to select for adaptive traits alongside productive traits in other (more favourable) environments. Indeed, estimates can be made of the relative efficiency of indirect selection in a different environment compared to direct selection in the target environment. Determinants are the genetic correlation and heritabilities of the trait in the different environments. The higher the genotype-environment interaction, the less effective is the indirect selection.

In some of the dairy work on genotype-environment interaction it was found that the USA 'low' environment (lower input management under conditions of climatic stress) was a better predictor of performance in other country environments. A USA data file restricting daughter information to low herd/year/season USA environments would be useful for across-country evaluation. Procedures to incorporate such 'foreign' evaluations should be explored to improve the accuracy of genetic evaluations of Holstein populations in other countries.

In intensive animal production systems large productivity responses to environmental improvements are often advantageous. However, such systems would be very susceptible to disturbances, e.g. climatic change, feed quality problems, or disease. Lower sensitivity to environmental change is useful for low external input systems and in harsh climates. In such cases there is less incentive to improve animal husbandry, due to the animal's relatively lower response to improved conditions. Before environmental sensitivity of productive traits can be included as part of genetic selection, more is required to be known on the shape and variation of reaction norms for important traits over different time horizons and for different environmental descriptors. This is true for breeds bred in favourable climates and also breeds originating in less favourable environments that show robust production parameters across different conditions.

Selection methods need to be improved to allow single breeds to have comparative advantage across environments. The reaction norm function can be used to predict breeding values for a trait, given a certain environment. Breeding values for reaction norm parameters can be predicted, if phenotypic values of a large number of offspring in a reasonably wide range of environments are available. These breeding values could be used to monitor the environmental sensitivity of a trait in a population, and to select for either high or low environmental sensitivity in the trait (the expression of a trait being responsive to environmental improvements, or being stable over favourable to less favourable conditions).

The importance of genotype-environment interactions in breed decision making for different environments is most clearly seen when breed substitution or upgrading is attempted in less favourable environments. The impacts on local breeds of indiscriminate or poorly informed breed importation can be notorious in terms of genetic erosion and in extreme cases worsening livelihoods of local breed keepers.

Three important issues arise from an interpretation of the significance of genotype-environment interactions for AnGR conservation. Firstly, before AnGR management decisions can be based (even in part) on the comparison of breeds' phenotypic performance in contrasting environments the validity of such comparisons has to be assessed. The animal science literature is full of papers that claim to make breed comparisons where sample sizes are so small as to be unrepresentative of the breed. The development of robust breed comparison protocols is required to guide those wishing to make breed comparisons across environments for AnGR management decision purposes.

Secondly, although genotype-environment interaction templates are based on single trait phenotypic comparison of breeds, breeding decisions would need to consider a series of traits important to the livestock economy of the environment into which breeds might be introduced.

Thirdly, using genotype-environment interaction types as templates in breed comparisons helps in the interpretation of whether the characterisation information gives rise to incentives for matching of breeds to environments, for substitution of breeds, or for environmental improvement. For example, where the interaction effect is greater than the genotype effect, which is in turn greater than the environment effect, there is a strong incentive to match breed to environment. Whilst, where the environment effect is greater than the genotype effect there is a strong incentive to improve less favourable environments (see Table 2).

**Table 2. Implications of different types of genotype-environment interactions for AnGR management when introduced and local breeds (genotypes A & B respectively) are compared in two environments (X the environment within which the introduced breed was selected and Y the environment to which the local breed is adapted).**

| Type of GxE* | Implications for AnGR management |
|---|---|
| G > E > I | • Within and between breed ranking similar over environments<br>• Comparative advantage of introduced breed in both environments<br>• This is the assumed type of GxE behind most breed importation<br>• Allows selection in few environments for use in many<br>• Incentive to improve less favourable environments |
| E > G > I | • Within and between breed ranking similar over environments<br>• Little comparative advantage of introduced breed in both environments<br>• Strong incentive to improve less favourable environments |
| E > I > G | • Some comparative advantage of local breed in environment 'Y'<br>• Type of GxE where adaptive traits important precursors of productivity<br>• Careful assessment of the value of 'I' required before breed substitution or upgrading attempted<br>• Incentive to improve environment<br>• Improving the environment may alter the ranking of breeds performance |
| G > I > E | • Marked difference in response by breeds to environmental differences<br>• Adaptive characteristics important<br>• Breed ranking not valid across environments<br>• Selection required in different environments<br>• Incentive to improve environment |
| I > E > G | • Marked difference in response by breeds to environmental differences<br>• Adaptive characteristics important<br>• Breed ranking not valid across environments<br>• Selection required in different environments<br>• Strong incentive to match breed to environment |
| I > G > E | • Marked difference in response by breeds to environmental differences<br>• Adaptive characteristics important<br>• Breed ranking not valid across environments<br>• Selection required in different environments<br>• Greater incentive to match breed to environment than to improve environment |

* G = genotype; E = environment; and I = interaction.

## 10. Climate change

To date the effects of climate change on agriculture are not clear and even less is known about the effect on livestock production. Studies have focused on predictions of the effects on agriculture and livestock rather than examination of the evidence of effects, let alone differentiated effects, on AnGR. Intensive livestock production systems have more potential for adaptation through the adoption of technological changes, whereas for pastoral systems, where the rate of technology adoption is low, more risk is perceived.

Although heat tolerance may be bred in to productive breeds this strategy may not be consistent with maximising production potential. At higher temperatures, it may be difficult to develop breeds that remain productive, species substitution could be an option in this case.

## 11. Management of animal genetic diversity

Important differences occur in the way breeding populations are affected by the same environmental effects leading to AnGR diversity loss and genetic erosion. AnGR with adaptive attributes at the animal level have high option value and therefore significant opportunity costs arise as these traits and breeds are lost. Evidence demonstrates that such AnGR are often susceptible to wider environmental effects (socio-economic and agro-ecological determinants). Thus, as in the case studies mentioned above genetic adaptability to local environments (generally biophysical determinants) is being lost due to differential impacts of wider environmental effects (generally socio-economic and agroecological) on AnGR.

Livestock keepers' breeding decisions do mediate negative environmental factors and have ensured the survival of local AnGR. However, evidence has been presented here in Section 2 of the over-riding and differential nature of some environmental effects on AnGR. For example, for poor livestock keepers - often the guardians of AnGR with significant option value - their main private coping strategy against negative environmental effects is to sell their livestock and this often results in slaughter.

In addition, clear evidence is available to challenge the assumption of "economic rationality" on behalf of such traditional and non-market oriented livestock keepers. Such assumptions hinder the explanation of their AnGR management decisions. Such livestock keepers maintain AnGR for economic and for socio-cultural reasons. Therefore, conservation initiatives can benefit from the willingness of livestock keepers to maintain breeds of high option value for socio-cultural reasons.

It has been noted here that documentation of the differential impact of environmental effects such as disease outbreaks, floods and disasters and agroecological changes on breed diversity is lacking. Although some such effects are beyond human control, consideration of the likelihood of such events and of the differential impact on components of AnGR is required so that AnGR management strategies to avoid differential impacts can be formulated. This is particularly so where direct or indirect effects of the policy framework have led to marginalisation of valuable AnGR into areas susceptible to short-term environmental changes and shocks. Safe minimum population size estimates for conservation purposes need to take the scale of such environmental effects into account. Contingency plans are required for re-stocking with appropriate livestock (from adjacent zones) to relieve livelihood impacts and to maintain stocks of local breeds.

Appraisals and rural inquiries are necessary to understand how environmental effects act within causative pathways, and from there develop AnGR conservation and management strategies. The case studies demonstrate the importance of socio-economic determinants, including policy frameworks, affecting both livestock keeper breeding decisions and AnGR inventories. The response of specialised producers to increasing demand for animal products and the support given by policy institutions have led in different ways to reductions in the stocks of local AnGR. The opportunity cost of the lost AnGR option value has not been estimated.

Such considerations are brought into sharp focus through recognition of the need to develop breeds capable of fulfilling needs for efficient animal production under conditions of negative climate change. In order to first identify and analyse, and then to rectify causes of genetic erosion in AnGR inventories of important option value, a clear understanding of the inter-relation, sequence and net effects of environmental factors is required.

Case studies of genetic erosion are needed to provide some evidence of the feedback processes altering the policy framework in favour of AnGR conservation and improved management. It is probable that far more than simply stating the quantitative aspects of AnGR loss is required. The causes of AnGR loss, the costs and benefits of processes leading to AnGR loss and the negative socio-economic and cultural impacts have to be identified, estimated and communicated.

## 12. Conclusions - knowledge gaps and research questions

Significant knowledge gaps and research questions have been identified through this review. These are set out below under the themes of breeding decisions for different environments and the impact of environmental effects on aggregated levels of AnGR (breeding populations).

### *12.a. Breeding decisions for different environments*

- The development of robust breed comparison protocols is necessary to guide those wishing to make breed comparisons across environments for AnGR management decision purposes. From the scientific literature reviewed here it is noted that many of the environmental effects studies at the individual animal level have been performed on a very small number of animals and the inferences of between breed differences lack validity;
- Identification and quantification of the determinants of the effectiveness of indirect selection including genetic correlation and heritabilities of the prioritised traits in the different environments is required;
- The procedures required to incorporate ‘foreign’ evaluations to improve the accuracy of genetic evaluations of animal populations in other countries (with particular reference to dairy cattle) need investigated;
- Determination of the shape and variation of reaction norms for important traits over different time horizons and for different environmental descriptors;
- Prediction of breeding values for reaction norm parameters using phenotypic values of a large number of offspring in a reasonably wide range of environments;
- Empirical evidence is needed on how environmental sensitivity is affected by selection for high phenotypic value in presence of genotype-environment interaction, with or without simultaneous improvement of the environment;
- Evaluation of the stability across production environments of genetic effects important in crossbreeding.

### *12.b. The impact of environmental effects on aggregated levels of AnGR (breeding populations)*

- Careful assessment of introduced and local breeds’ indicative performance characters in the selection and local environments to assess the level in interaction effects, genotypic and environmental effects;
- Using the genotype-environment interaction types templates in breed comparisons to explore incentives for matching of breeds to environments, for substitution of breeds, or for environmental improvement;
- Documentation and analysis of the differential impact of environmental effects such disease outbreaks, floods and disasters, and climate change on AnGR diversity is required to identify breeds with high option value at risk from these factors;

- Documentation and analysis of the differential impact of environmental effects such agroecological and socio-economic changes on AnGR diversity is required to identify breeds with high option value at risk from these determinants;
- Estimation of the opportunity cost of the lost AnGR option value in order to compare cost of conservation with cost of genetic erosion;
- Formulation of AnGR management strategies to avoid differential impacts of environmental effects (agro-ecological and socio-economic);
- The quantification and distribution of the costs and benefits of processes leading to AnGR loss and the negative socio-economic and cultural impacts should be assessed.