Genetic diversity and sustainable management of animal genetic resources, globally

E. Fimland

Nordic Gene Bank Farm Animals, Department of Animal and Aquacultural Sciences,
*P.O. Box 5003, 1432 **Aas**, Norway*

Summary

General trends of development imply an increasing uniformity of animal genetic resources, caused by the loss of endangered breeds and increased inbreeding within commercial breeding populations. The implications of these trends point to a reduction in the genetic diversity of the animal genetic resources, which may reduce possibilities for utilization in the future, while at the same time a dramatic change in environmental production conditions can be observed. In order to change this developmental trend, sustainable management of animal genetic resources must be promoted globally. The fundamental issues for such sustainable management are illustrated by the principles given in the Convention on Biological Diversity. In order to accomplish sustainable management of these resources, the following actions must be taken:

- The development of policies to promote national and global responsibility for maintaining genetic diversity, which will not be addressed within this paper
- The development of knowledge as a fundamental concept to impose sustainable management principles on these animal genetic resources. This will be dealt with in this paper. A more complete description of these features can be found in Woolliams *et al.*, 2005 in (Sustainable Management of Animal Genetic Resources).

Résumé

Les tendances générales de développement actuel prévoient une uniformité des ressources génétiques animales, due, d'une part, à la perte des espèces menacées d'extinction et d'autre part, au développement des croisements génétiques au sein des populations commercialisées pour l'élevage.

Ceci mène à une restriction de la diversité génétique des ressources animales, ce qui pourrait compromettre leur utilisation possible à l'avenir. A côté de cela, les conditions environnementales de production sont également radicalement changeantes. Pour pouvoir faire évoluer ce mode de développement de manière positive, il est plus que nécessaire d'imposer un management durable des ressources génétiques animales, à l'échelle mondiale. Le fondement d'un tel développement durable est mis en avant par les principes cités par la Convention sur la Biodiversité. Pour atteindre un management durable de ces ressources, certaines conditions sont nécessaires:

- Une responsabilité à la fois nationale et internationale pour conserver la diversité génétique - règles, qui ne seront pas traitées dans ce document
- Développer les connaissances, fondement de base pour imposer le développement durable de ces ressources génétiques animales; sujet qui sera débattu ici. Une plus complète description de ce dispositif peut être consultée dans Woolliams *et al.*, 2005 (Sustainable Management of Animal Genetic Resources).

Resumen

Las tendencias generales de desarrollo actualmente preven una uniformidad de los recursos zoogenéticos debido, por una parte a la pérdida de especies en vía de extinción y por otra al desarrollo de cruces genéticos dentro de las poblaciones para comercialización. Esto nos lleva a una restricción de la diversidad genética de los recursos animales, lo que podría comprometer su utilización en el futuro. Al mismo tiempo las condiciones ambientales de producción también están cambiando radicalmente. Para permitir la evolución de este tipo de desarrollo de manera positiva, será necesario imponer una gestión sostenible de los recursos zoogenéticos a escala mundial. La base de este desarrollo

sostenible se recoge dentro de los principios estipulados en la Convención para la Biodiversidad. Para alcanzar una gestión sostenible de estos recursos son necesarias ciertas condiciones:

- Responsabilidad tanto nacional como internacional para la conservación de la diversidad genética – normas que no trataremos en este documento.
- Desarrollar los conocimientos y los fundamentos de base para imponer un desarrollo sostenible de estos recursos zoogenéticos, este tema será tratado en el artículo. Una descripción más detallada de este dispositivo se puede consultar en Wooliams, J.A. *et al.* 2005. Sustainable Management of Animal Genetic Resources. Nordic Gene Bank Farm Animals ISBN 92-893-1089-8.

Keywords: *Animal genetic resources, Sustainable management, Maintain genetic diversity, Optimal selection, Conservation.*

Introduction

In addition to maintaining diversity, the Convention on Biological Diversity (CBD) also intends to activate genetic resources (GR) for food production, which may impact on the sustainable management of all farm AnGR, including:

- Sustainable useage.
- Sufficiency of conservation.
- Fair and equitable sharing of benefit.
- National responsibility.

The objectives of the CBD can be accomplished in two ways: via political incentives and/or directives/acts on the one hand; and through knowledge, analysis of future consequences and invention of technological tools to avoid damage caused by insufficient breeding programmes on the other. In addition, sufficient conservation of endangered breeds must be undertaken in such a way that genetic diversity among breeds can be maintained.

The Nordic Gene Bank Farm Animals (NGH) focuses on developing the knowledge needed to accomplish the sustainable management of AnGR, based on extensive cooperation with, among others:

- National ministries of agriculture.
- National gene resource committees or other bodies appointed by the national authorities to organise the national conservation of AnGR, within the scope of available budgets.

- National breeding organisations, breed societies, etc.

NGH has directed increasing focus towards the elements needed to secure sustainable management of AnGR.

Elements Needed for Sustainability

The following factors influence sustainable management of AnGR:

- Inbreeding, DF = 1/ N_e a function of the efficient population size.
- Maintaining alternative breeds.
- Selection on a complete set of traits.
- Interaction between environment (production systems) and genetic effects.

The first two points encompass the requirement of maintaining diversity of farm AnGR and can be accomplished by the following means:

1. Avoidance of inbreeding:
   - Optimal selection based on the contribution theory that needs are equal for all breeds.
   - Maintaining a sufficient number of breeds to secure between-breed diversity, which provide new genes for immigration/exchange from other breeds. This requires several alternative breeding populations.

2. Conservation of breeds:
   - Activating properties of certain breeds for developing branded food products.
   - Ensuring sufficient conservation to secure maintenance of important genes for future use.
   - Conservation of historical/culturally important breeds.

3. In order to maintain the population of farm animals as a healthy production unit, the breeding goal must encompass the traits of both marketable products and those important for the functionality of the individuals belonging to the population. This implies:
   - Weighting factors for the traits must counterbalance the negative response via genetic correlations with vital traits of functionality, or proper trait restriction must be used as a selection tool.
   - By using reproduction, health and survival traits in the selection goal properly, unexpected problems caused by rapid changes in the frequency of unfavourable alleles/deleterious genes may be avoided,

and inbreeding depression in fitness traits may also be reduced.

To illustrate the point, the realised ΔG for mastitis in Norwegian Red is shown in figure 1. Breeding programs can be designed in a way that gives a positive response to such traits as mastitis. Similar responses can be shown for non-return rates and other health problems in the breed in this example.

4. The last important factor impacting sustainability is the occurrence of interaction between production systems and genotypes. An international 'regulation' of exchange of AnGR should focus on this interaction and its social and economic consequences for the recipient population in the long run.

It would seem appropriate to copy some of the principles of the national legislation relating to the trade of goods in several countries, which put responsibility on the seller to sell an appropriate product. Such requirements could easily be included in a standard agreement for transferring genetic material of farm animals.

When the testing of the breeding animals and the production of the offspring are performed in the same environment or in the same production system, the interaction between genotype and environment or production system can usually be ignored. However, when the offspring is exported, the environment in the importing country may be quite different from the test environment of the parents. Besides, a lack of adaptation of the breeds to the environment in the importing country might have a negative effect on fitness traits leading to disappointing production figures. An international regulation of exchange of farm animal genetic resources should focus on the existence of possible interactions and the long-term social and economic consequences for the importing country. It might undermine the livelihood of farmers in the importing country. Such imports often result in the erosion of local livestock systems and often the livelihoods of entire groups of people are destroyed. It has to be realized that as much as 70% of the world's rural poor (approximately two billion people) keep livestock to meet the food demands of their families. In these communities, livestock diversity contributes in many ways to human survival and wellbeing (Drucker, 2002). Increasing production volume may also increase waste output. The considerable volumes of waste produced by large-scale, high-density livestock operations can cause severe soil, water and air pollution (Cunningham, 2003). The most important pollutants giving rise to concern are nitrogen, phosphorous, various heavy metals and greenhouse gasses such as methane and nitrous oxide. If the recycling of manure and urine in agriculture is not firmly regulated, considerable environmental damage may arise. The strong focus on environmental issues in several countries may lead to regulations that minimize the output of wastes from livestock systems. Such regulations may require other genotypes than those favoured by the present breeding goals which focus on maximizing yield. This means that breeding
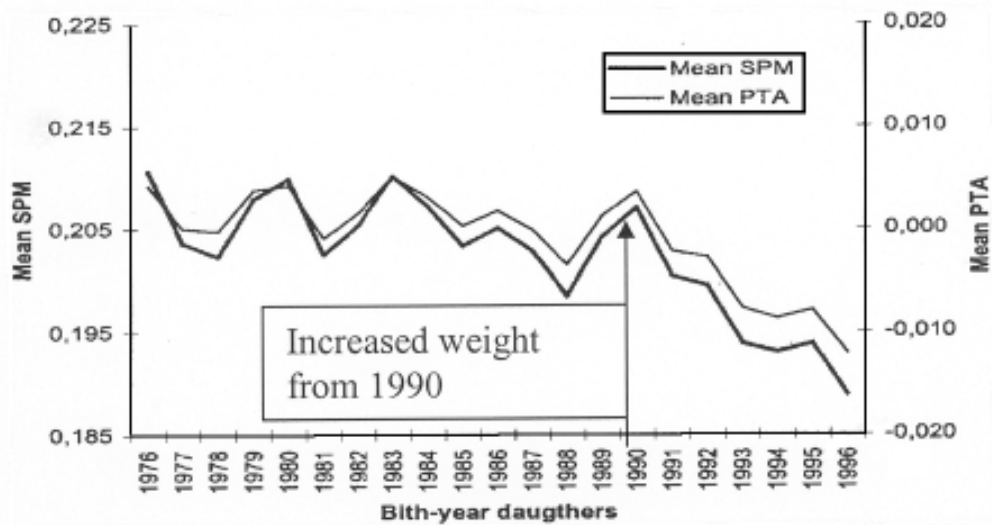

Figure 1. Plot of average sire posterior mean (SPM) in the probability scale (threshold model) and mean predicted transmitting ability (BLUP-PTA) of sires by birth-year of daughters for mastitis.

programmes that maximize production volume per animal may lead to a reduction of the environmental quality for that society.

Food Security and Safety

Woolliams (2006) discusses the fundamental importance of farm animal genetic resources for food security and safety. The general answer is that livestock development works best when all strategies are co-ordinated and work in the same direction. For example, fertility in dairy cattle tends to decrease as milk yield increases. An established consequence of infertility is an increase in greenhouse gas emissions from the production system per litre of milk produced. The effectiveness of any management solution will be compromised when selection increases yield without taking into account the genetic merit for fertility. In this instance, the overall utility of the system will not be optimised (Woolliams 2006). Genetics can play an important role in the dynamics of the populations caused by genetic selection, and one should use genetic options, where they exist, as part of the solution to improve security and safety.

To meet the challenges to food security arising from the increased global demand and the threats from global warming, livestock breeding must be included as a component of the solution. In the long term, unsustainable management of animal genetic resources may lead to an increased risk to food security and safety.

Knowledge as a Driving Force for Sustainability

Since the food coming from farm animals accounts for 40-50% of human caloric intake, and in many countries much of this food originates from the commercial or mainstream breeds, the maintenance of genetic diversity within these breeds is becoming increasingly important. As the number of breeds used in food production continues to decline, there is an increasing risk of some genetic failure. The loss of breeds contributing to our food supply directly diminishes the aspect of food security inherent in maintaining a diversity of food resources. Thus, major breeds which have "no alternative" for immigrant genes from other breeds, have to invest in tools and strategic measures to avoid the risk of genetic failure, as part

of the running breeding programme. Investments in risk management measures for running breeding programmes are not well documented.

Therefore, I would like to discuss more thoroughly the importance of managing the mainstream breeds by maintaining their future genetic diversity as part of breeding programmes.

Present Status

The classic measure for genetic improvement per generation is accuracy (the square root of heritability, h) times the genetic selection differential expressed in real units of the trait ($i\sigma_g$);
$\Delta = hi\sigma_g = h^2 i\sigma_p^2$, in which h is the correlation between genotype g and phenotype p, h^2 is the regression of g on p, i is the selection differential and σ_g and σ_p^2 are genetic standard deviation and phenotypic variance, respectively. Efficient methods for registration of lineage and such traits as performance, fertility, health and survival for individuals in a population have been implemented. At the same time, efficient methods for breeding value estimation were developed, which linked the individual's traits to all relatives. These methods were based on the principle of "Best, Linear Unbiased Predictions" (BLUP), (Henderson, 1976).

Due to the before mentioned development, a limited number of certain individuals and their relatives can easily come to dominate as parents in future generations. As a result, the breed will eventually consist of animals originating from fewer and fewer families. As time passes, the average degree of relatedness between parents increases and thus, the inbreeding rate will increase.

Developing a Sustainable Breeding Theory

An important discovery within genetic theory was the effect of selection on genetic variation. This was developed by Bulmer (1971) and shows that systematic selection of parents results in reduced genetic variation among their offspring. After four to five generations with the same selection intensity, the reduction will stabilise. In practical cattle breeding work, Fimland (1979) showed that this reduction could amount to 20 – 30%, depending on the selection intensity and accuracy. Systematically, intensive selection thus leads to the stabilisation of

genetic variation at about 70 - 80% of the level of variation achieved with random mating and no selection.

The next step towards developing a more realistic foundation for breeding work was the discovery of the dynamic traits of the additive kinship matrix **A**, by Hill (1974), Henderson (1976), Thompson (1977) and Wray and Thompson (1990). The elements in the **A** matrix generate covariance or degrees of relatedness between all individuals in a pedigree for the respective population, as well as the individuals' inbreeding status along the diagonal of **A**. When determining **A** from the "base" generation, one can identify gene transfers throughout all individuals in a lineage; sires to sires, sires to dams, dams to sires and dams to dams, from the base generation to the present population. In addition, one gets an overview of the individuals that have provided a lasting genetic contribution to genetic improvement, and of those individuals that no longer are considered as contributors to genetic improvement.

The latest major step of this development was the establishment of the unique "genetic contribution" theory put forward by Woolliams and Thompson (1994), which also provided a tool to estimate values for ΔG and ΔF. The two defined factors that determine genetic improvement and inbreeding rate are:

- A factor, r, which is the additive genetic contribution from an individual in a pedigree to today's population, where the corresponding element of **A** is a function of r. When r > 0, the individual is a contributor to genetic improvement, but when r = 0, the individual has not contributed to the genetic improvement of today's population. The sum of *r* of all dams contributing to the present population is 0.5. The same applies to the sires contributing to the present population.
- The breeding value of an individual is comprised of: $g = \frac{1}{2} g_s + \frac{1}{2} g_d + s$
  where g, g_s, g_d are the additive breeding values for the individual, sire and dam, respectively; and s is the individual's unique additive breeding value for the trait, consisting of the individual's unique gene combination in addition to the additive breeding value transferred by the parents. Variation of this element, s, can amount to more than half of the additive genetic variation of present populations. The expression is used because if selection is carried out in the parent generation, the additive genetic variation that is transferred from the parents to their offspring will be less

than when using random mating and no selection among parents (the so-called Bulmer effect). The value of s is often called the "individual's sampling term".
It was shown that:

1. ΔG = sum of r multiplied by s for all individuals in the pedigree who pass on genes to individuals in today's population (ΔG = Σ r x s). This shows that genetic improvement is a direct product function of the individuals contributing genes (r > 0) and the corresponding value of s, which expresses the individual's unique gene combinations, i.e., the genes that are not additively passed down from the parents or from more distant relatives in the pedigree.
2. ΔF = sum of r squared for all individuals who contribute genes to individuals in today's population ($\Delta F = \frac{1}{4} \Sigma r^2$), under certain assumptions, e.g. random mating.

Due to the dynamics of breeding work, if one goes back five to seven generations in the pedigree, the contribution from those parents passing on genes to present-day and future individuals will be the same for each of these ancestors. This means that the genetic contribution of previous "matadors" (extensively used) breeding animals that have contributed to a large share of genes in today's population cannot be changed in a closed breeding population. In a closed population, genetic change will take place for those genes that can contribute to new gene combinations. Such new gene combinations can only occur via the "gene base", which is identified by the individual's sampling term. The individual's sampling term is the individual's specific and unique set of genes, and thus represents the foundation for future genetic renewal that can occur within closed populations. Fifty per cent of genetic variation is fixed through previous selection of parents and earlier relatives. Only in the most recent generations will genetic contributions be affected by the accuracy of the breeding value and the individual's selective benefit. It is thus obvious that an individual contributing to sustainable improvement has a sampling term that is larger than the average of its parents' breeding value. The characterisation of this genetic diversity shows a resource potential for the respective trait and population. Theoretically, an individual's sampling term as an infinite resource will only exist for traits consisting of an infinite number of *loci*. For traits with only one *locus* or few *loci*, selection will rapidly approach fixation, and thus be depleted of its genetic variation.

In closed populations with intensive selection and the use of few sires, the long-term contribution and a large share of the genes will be provided by only a few individuals. In such cases, the effective population size, which is $N_e = 1/(2\Delta F)$, will be relatively small. Since the selection space for breeding work is $2N_e i h^2 \sigma_p^2$, breeding programmes with small effective population sizes (N_e) will result in less total improvement than breeding programmes that secure larger effective population sizes. It has been indicated that moderate selection (about 50%), especially in the first generations, will ensure maximum genetic improvement in the long run. It should be well known that intensive selection in the start-up phase of a breeding programme leads to the loss of numerous beneficial genes in the first few generations, due to the effect of linkages between *loci*. A more moderate selection intensity early in the programme will help to 'break apart' these linkages as time progresses, thus enabling more beneficial genes to be passed on to future generations, (Alan Robertson personal communication from 1974).

One way to regenerate genetic variation is to enable immigration of genes from various other populations. This is the most effective way to provide new genetic variation, especially when the external population contains more beneficial genes than the mother population. However, immigration from other, similar populations can also lead to improved genetic variation, especially for inbred mother populations. For these, genetic variance would be $(1-F)\sigma_g^2$, where F is accumulated inbreeding. In such cases, the new supply of genes can "break apart gene pairs identical by descent" that have been inherited from the same ancestor and replace these with genes that are either more beneficial or have the same functional value. In either case, inbreeding will be discontinued, thus revitalising the genetic variation within the population.

Optimised election is the maximisation of the selection differential, with the restriction that ΔF is less than, e.g. 0.5%, in which case $N_e = 100$ animals. Optimisation is achieved by maximising the selection differential for the potential parents by using a mating strategy that keeps the inbreeding rate in the next generation below a given value, e.g. 0.5%. The process of optimisation implies determining which animals to use in breeding, and deciding on the relative genetic contribution of each of these, c_i. This includes, for example, determining the relative share of semen provided by each proven sire. If this value is expressed as c_i, optimised selection will result in maximised correlation between c (contribution to next generation) and r (long-term contribution).

Effect of Selection

In classic breeding, genetic improvement is accuracy (h) times selection intensity (i) times genetic standard deviation for the trait. Note that the term "accuracy" here is an expression relating to the accuracy of an individual's breeding value (g). Due to uncertainty and other factors, certain selected individuals may not contribute to future genetic gains. For example, it has been shown that some bulls selected as breeding sires generate progeny which for various reasons do not contribute to genetic improvement.

By calculating the contribution to genetic gain ($\Delta G = \Sigma r \times s$), where r is the long-term contribution, and s is the sampling term, one sees that these bulls (with r = 0) do not contribute to genetic improvement.

This implies that:

1. Long-term contribution (r) correlates better with the breeding value of the individual's sampling term (s) than with the individual's breeding value (g). In other words, the individual's selectivity is more closely tied to the value of the sampling term (s) than to the individual's breeding value (g).

2. Additive genetic variation from g_f is less than half of the variation of s – the individual's sampling term in populations under selection.

3. Due to restrictions on ΔF, optimised selection leads to greater accuracy with regard to the contribution to genetic gain than when applying classic breeding theory, in other words, this maximises the correlation between c (contribution to next generation) and r (long-term contribution).

4. Optimal selection secures "new genes" with selective benefits from potential parents' sampling term, s, and which have not been previously expressed by animals in the pedigree. Such animals will contribute to sustainable breeding gain in future generations.

An analysis done by Avendano *et al*. (2004) shows the following results:

∙ ∙

1. Correlation squared between the long-term contribution (r) and estimated sampling term (s) is 0.84
2. Correlation squared between the long-term contribution (r) and estimated breeding value (g) is 0.43

This means that restricted inbreeding in breeding programs improves the efficiency of breeding operations.

It was also shown that the effect of selection in an optimised selection strategy was 0.92, compared to 0.50 in ordinary BLUP selection, i.e., nearly twice as much. Furthermore, optimal selection gave 20% more genetic improvement than ordinary selection. These results confirm that, when selecting parents, restrictions on expected ΔF in the next generation reflect the individual's sampling term, s, rather than the breeding values of the individual's parents.

Several analyses have shown that restrictions on the rate of inbreeding can lead to the apparent loss of phenotypic selection differential. Restriction of inbreeding in the optimal selection scheme leads to the selection of alternative parent animals with a higher probability of contributing to the renewal of genetic variation. It is also more probable that these breeding animals will contribute to the long-term genetic gain (r > 0) than animals selected for ensuring a maximum 'phenotypic' selection differential. When placing restrictions on inbreeding rates for the next generation, the net effect is that the product of selection differential times accuracy is maximised. This implies that optimal selection in general includes the use of breeding animals that lead to greater selective benefits and higher probability for a long-term contribution to genetic gain. The result is more efficient genetic improvement than when selection is merely based on BLUP values.

Conclusions

Optimal selection focuses on:
1. The individual's selectivity, which is dependent on the relative share of genes (r) and a positive additive value of the individual's sampling term (s > 0).
2. Maximising the probability that the selection of parents gives unique, new genes that contribute to genetic improvement in coming generations, i.e. finding potential parents with a considerable probability of providing unique and new genes from their sampling term.

3. Genetic improvement requires that, new, unique and beneficial genes be introduced from the sampling term of each new generation of potential parents.
4. Selection for traits with limited number of *loci* will gradually reduce the genetic variance as *loci* become fixed. In traits with infinite number of *loci* the random sampling term with its genetic variance seem to be unaffected by selection. However the intense selection of the parent implies that the parent's contribution to the next generation of the genetic variance will be less than ½. Thus, the sum of the random sampling term of genetic variance and the part coming from the parent will be less than the original genetic variance with no directional selection of the parents, i.e.the Bulmer-effects.
5. The only practical way to break long time inbreeding is to immigrate genes from other breeding population. Such refreshing of blood to local breeds has been done in many breeds during the history. The question of where to find a breed that can be accepted for use, may become a question of life or death for some populations.

List of References

Avendano, S., J.A. Woolliams & B. Villanueva. 2004. Mendelian sampling terms as a selective advantage in optimum breeding schemes with restrictions on the rate of inbreeding. Genet. Res., Camb. 83, 55-64.

Bulmer, M.G. 1971. The effect of selection on genetic variability. The American Naturalist 105, 201-211.

Chesnais, W. Fairfull, J. P. Gibson, B.W. Kennedy & E.B. Burnside. 1994. Proceedings of the 5th World Congress on Genetics Applied to Livestock Production, Guelph, Ontario, pp. 127-134.

Cunningham, E.P. (Ed.). 2003. After BSE – A Future for the European Livestock Sector. EAAP publication no. 108.

Drucker, A.G. 2001. The Economic Valuation of AnGR: Importance, Application and Practice. In: Proceedings of the workshop held in Mbabane, Swaziland, 7-11 May 2001.

Fimland, E. 1979. Zeitschrift für Tierzüchtung und Züchtungsbiologie 96, 120-134

∙ ∙

・ ・

Henderson, C.R. 1976. A simple method for computing the inverse of a numerator matrix used in prediction of breeding values. Biometrics 32, 69-84.

Heringstad, B., R. Rekaya, D. Gianola, G. Klemetsdal & K.A. Weigel. 2003. Genetic change for clinical mastitis in norwegian cattle: a threshold model analysis. J. Dairy Sci. 86: 369–375.

Hill, W.G. 1974. Prediction and evaluation of response to selection with overlapping generations. Animal Production 18:117-139.

Simm, B. Villanueva, K.D. Sinclair & S. Townsend (Eds). 2004. Farm Animal Genetic Resources., BSAS Publication No. 30. Nottingham University Press, Nottingham NG11, 0AX. ISBN 1-897676-15-8, SB, pp. 345.

Thompson, R. 1977. The estimation of heritability with unbalanced data: ii. data available on more than two generations. Biometrics, Vol. 33, no. 3, pp. 497-504.

Woolliams, J.A. & Thompson R. 1994. In: Proceedings of the 5th World Congress on Genetics applied to Livestock Production, Guekph, vol. 19.

Woolliams, J.A. 2006. Sustainable Livestock Breeding – Food Security and Safety. "Nordic GENEresources", ISBN 92-893-1153-3, *www.nordgen.org/publikasjoner/ nordiskegenressurser.htm*

Woolliams, J., P. Berg, A. Maki-Tanila, T. Meuwissen, E. Fimland. 2005. Sustainable Management of Animal Genetic Resources- As: Nordic Gene Bank Farm Animals. ISBN 92-893-1089-8, pp. 95.

Wray, N.R. & Thompson R. 1990 Prediction of rates of inbreeding in selected populations. Genet. Res. 55, 41-54.

・ ・

Integrating policies for the management of animal genetic resources with demand for livestock products and environmental sustainability[1]

H.D. Blackburn

*National Animal Germplasm Program, National Center for Genetic Resources Preservation, ARS, USDA, **Fort Collins**, CO 80521, USA,*

Summary

Global recognition of the need to conserve animal genetic resources comes at a time when the livestock sector faces significant challenges in meeting the growing demand for livestock products and the mitigation of negative environmental impacts caused by livestock. In developing regions it would seem that portions of the growing demand for livestock products are being met by increasing animal numbers instead of achieving increases in production efficiency. Concurrently, extensive grazing and mixed crop-livestock production systems are largely responsible for significant greenhouse gas emissions and other forms of environmental degradation. Under the growing demand and environmental sustainability rubric there exists a need to garner maximum benefit from diverse animal genetic resources. These three areas; growing demand on animal products, environmental issues, and conservation of AnGR form a nexus that national policies must simultaneously consider. To advance this integration, a policy framework is proposed that consists of incentives to produce, a secure resource base (e.g., genetic resources, land tenure) and access to markets for outputs and inputs including technology. Within this framework a set of potential policies are suggested that promote conservation, livestock sector growth and environmental sustainability.

Résumé

La reconnaissance au niveau mondial du besoin de conserver les ressources génétiques animales arrive à un moment où le secteur de l'élevage se trouve à faire face à des défis importants tels que l'augmentation de la demande de produits et comment atténuer l'impact négatif sur le milieu du à l'élevage. Dans les régions développées il semblerait qu'une partie de l'augmentation de la demande de produits puisse être obtenue avec l'augmentation du nombre d'animaux au lieu d'essayer d'augmenter l'efficacité de la production. Au contraire, le pâturage extensif et les systèmes mixtes de production agriculture-élevage sont en grande partie responsables des émission de gaz de serre et d'autres formes de dégradation du milieu. Si nous considérons les normes au sujet de l'augmentation de la demande et la durabilité de l'environnement il faudra obtenir un bénéfice maximum des différentes ressources génétiques animales. Les trois domaines sont:
1. L'augmentation de la demande de produits d'origine animale.
2. Les problèmes de l'environnement.
3. La conservation des formes de AnGR comme point d'union pour les politiques nationales.
   Pour atteindre cette intégration il est nécessaire de créer un cadre politique qui prévoit des primes à la production, une ressources de base fiable (p.e. ressources génétique, propriété de la terre) et un accès aux marchés pour les produits et la technologie. Dans ce cadre on suggère d'inclure un ensemble de normes potentielles pour promouvoir la conservation, la croissance du secteur élevage et la durabilité du milieu.

Resumen

El reconocimiento mundial sobre la necesidad de conservar los recursos zoogenéticos llega en un momento en que el sector ganadero se enfrenta a

desafíos importantes como el incremento de la demanda de productos ganaderos y cómo atenuar los impactos negativos sobre el ambiente debidos a la ganadería. En las regiones desarrolladas podría parecer que una parte del aumento de la demanda de productos se podría conseguir con el incremento del número de animales en vez de intentar aumentar la eficacia de producción. Al revés, el pastoreo extensivo y los sistemas mixtos de producción agricultura-ganadería son en gran parte responsables de las emisiones de gas y otras formas de degrado ambiental. Bajo las normas de incremento de la demanda y sostenibilidad ambiental existe la necesidad de conseguir un beneficio máximo de los distintos recursos zoogenéticos. Estas tres áreas son:

1. Incremento de la demanda de productos animales.
2. Problemas ambientales.
3. Conservación de formas de AnGR como nexo para las políticas nacionales.

Para alcanzar esta integración es necesario un marco político que consiste en incentivos a la producción, un recurso de base seguro (p.e. recursos genéticos, propiedad del terreno) y un acceso a los mercados para los productos y la tecnología. Dentro de este marco se sugiere incluir un conjunto de políticas potenciales que promuevan la conservación, el crecimiento del sector ganadero y la sostenibilidad ambiental.

Introduction

During the past decade awareness concerning the contraction of animal genetic resources (AnGR) has increased, particularly through the reporting process of FAO's State of the World's Animal Genetic Resources (SOW; FAO, 2007). The SOW report highlights issues confronting the use and conservation of diverse animal genetic resources. It suggests that the major challenges for countries are to balance different livestock policy objectives that maintain animal genetic resource diversity, environmental integrity, increasing demand for livestock products, and contributions to rural development and poverty reduction. Given that AnGR are a component of the livestock sector, measures taken to conserve genetic resources should complement other initiatives designed to advance the sector. Nesting AnGR within livestock

development is necessary due to the environmental and economic development pressures that are currently placed on livestock industries, especially in the developing world. Principally, to meet the growing demand for livestock products, animal productivity needs to be increased and the environmental foot-print contained.

Two important driving forces are the unprecedented growth in demand for livestock products (Delgado *et al.*, 1999) and global environmental issues (de Haan *et al.*, 1997; Steinfeld *et al.*, 2006). Increasing demand for livestock products has spurred acceleration in industrial production systems and significant growth in poultry and swine production (Steinfeld *et al.*, 2006). In turn, such increases have or are having significant environmental impacts. In addition, the move to more intense industrial types of production systems coupled with increases in selection intensity contribute to the loss of animal genetic resources within those production systems.

The goal of this paper is to explore the major forces - product demand, environment and productivity - that impact AnGR and the type of policies that facilitate the integration of AnGR conservation, economic growth, and environmental issues. The paper approaches this by presenting an overview of the demand for livestock products, major environmental issues confronting the livestock sector, and how animal genetic resource use may change in relation to these forces. Given this discussion, a policy framework capable of addressing these three issues is presented and followed by several policy options that integrate the issues of demand, environment, and conservation.

Demand for Livestock Products and Growth of the Livestock Sector

Delgado *et al.* (1999) have estimated that total meat consumption in the developing world will increase from 88 000 000 metric tons in 1993 to 188 000 000 metric tons in 2020, a 4.2% per year increase. Such an increase in demand suggests that to keep pace with livestock product demand, per animal productivity will have to increase, production systems will have to intensify, and commercially viable genetic resources will have to be utilized more extensively (whether they are indigenous, exotic, or were developed for industrial production system use). In many production systems indigenous AnGR have been used to play

fundamental subsistence and sustainability roles in extensive and crop-livestock systems (Rege and Gibson, 2003). However, this position is and will continue to be challenged, potentially resulting in a further contraction or loss of genetic resources. Table 1 shows that the rate of increase in livestock production is not consistent across regions but progress is being made toward meeting the projected demands estimated by Delgado *et al.* (1999). Table 1 also shows the increasing importance of monogastric species, in agreement with SOW (FAO, 2007) and Steinfeld *et al.* (2006). However, when increased production is converted to per head productivity for cattle, milk, and small ruminants (Figure 1) it is apparent that not all regions are experiencing an increase, and most notably contributions from small ruminants and beef cattle are lagging in some developing regions. It is acknowledged that significant increases in monogastric species has occurred, but such information was not available in the dataset. FAO (2007) illustrates that producers respond to increasing demand by expanding herd size, diversification of production or processing, intensification of existing production patterns and increasing the proportion of off-farm income. It would appear from table 1 and figure 1 that producers are responding to demand signals primarily by increasing herd size, with some diversification of production and processing, and/or intensification of specific production systems (FAO, 2007; Steinfeld *et al.*, 2006).

Environmental Issues – A Global Concern

During the past 35 years the livestock sector has continually been placed in an adversarial position due to real or perceived negative impacts on the environment. Environmental issues have been and will continue to be a point of contention for livestock industries and how societies choose to utilize livestock species (de Haan *et al.*, 1997; Steinfeld *et al.*, 2006). Furthermore, the impacts livestock are having on the environment are occurring across all livestock production systems (extensive grazing, mixed farming, and industrial), species, and geographic regions. The breadth of this issue is dramatic and concerning, especially with regard to the livestock sector's need to meet further consumer demands. On a global scale, livestock impact the environment by overgrazing, climate change (soil organic matter oxidation and carbon release into the atmosphere), water resources depletion (through reduced recharge of ground water), and biodiversity loss via habitat destruction (Steinfeld *et al.* 2006; de Haan *et al.* 1997). Of particular concern, as Steinfeld *et al.* (2006) illustrated, is the total greenhouse gas emissions from enteric fermentation and manure that are greatest in Latin America, Sub-Saharan Africa, China, and South and East Asia (Figure 2). The species emitting the largest amounts of gases are cattle and buffalo produced in extensive grazing and mixed crop-livestock production systems. This result is surprising, as it was often assumed that mixed crop-livestock and extensive grazing systems were relatively benign contributors to greenhouse gas emissions compared to industrial systems. This finding has important ramifications because located in these production systems and geographic areas are significant portions of AnGR. As a result steps to mitigate environmental impacts will also impact these AnGR. While such results are of concern and warrant action, potential solutions to mitigate greenhouse gas emissions do exist. For example, Leng (1991) illustrated that improving ruminant diet quality, particularly in the mixed crop-livestock systems, can reduce greenhouse gas emissions.

In addition to greenhouse gas emissions, landscape degradation by grazing ruminants remains an important issue in Africa, Central and South Asia, and Central and South America. As a result of such pressures, Asner *et al.* (2004) suggest

Table 1. Annual percent change in production from 1994 to 2004 across developing regions.

Region/Product	Beef	Small ruminant	Pork	Eggs	Milk
Sub-Saharan Africa	2.8	4.1	2.0	2.1	3.1
Asia	18.8	6.7	4.9	7.7	4.5
Central – South America	4.3	-0.5	5.8	2.7	3.7
West Asia – North Africa	1.8	1.1	4.5	3.0	4.5

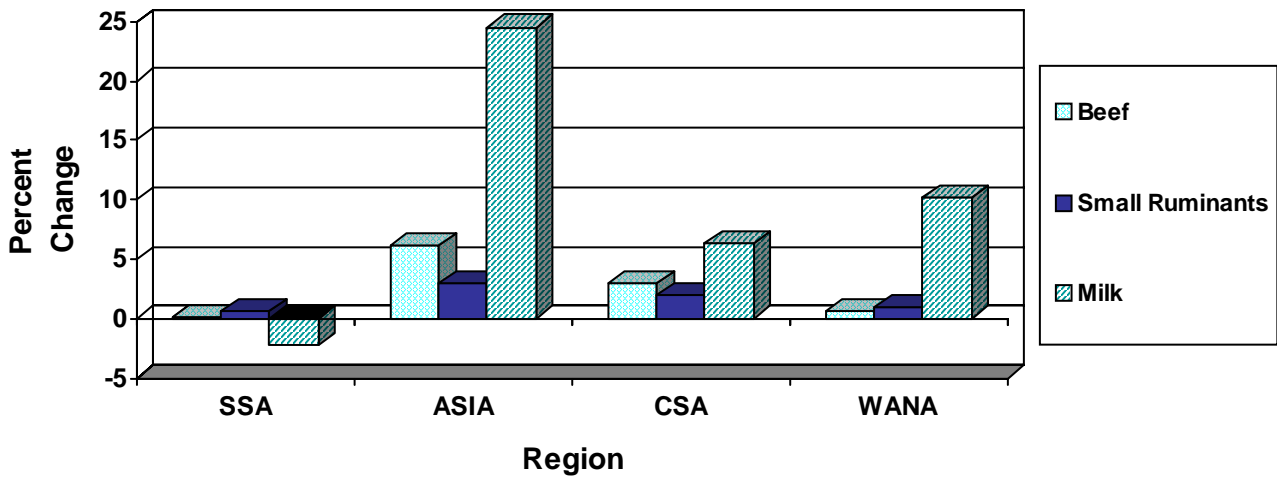Data source: H. Steinfeld, unpublished.

Figure 1. Annual percent change in production per head from 1994 to 2004 for Sub-Saharan Africa (SSA), Asia, Central and South America (CSA), West Asia and North Africa (WANA).
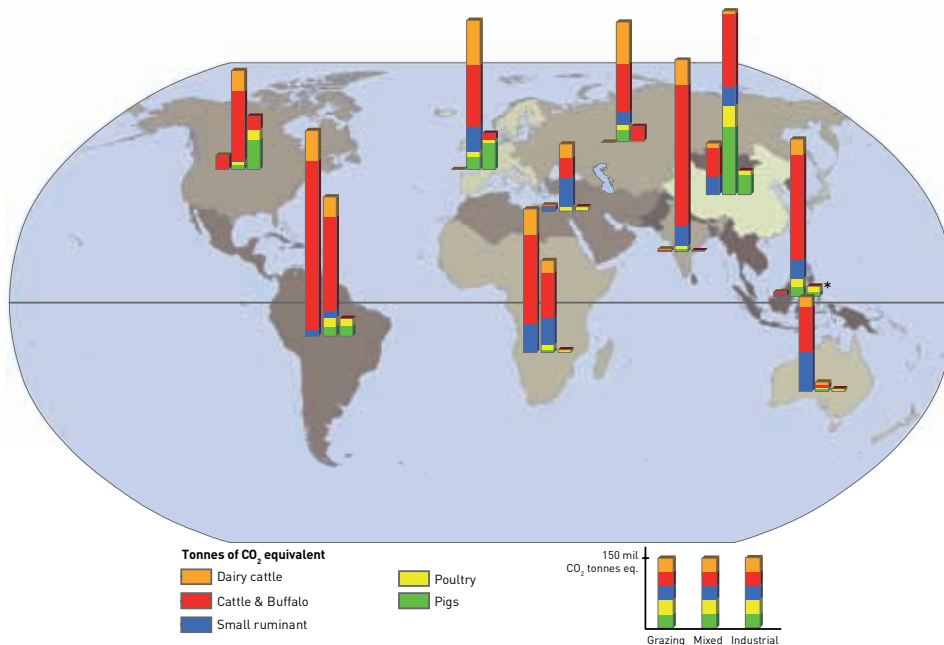

Figure 2. Total greenhouse gas emissions from enteric fermentation and manure per species and main production system. (Source: Steinfeld et al., *2006).*

three types of ecosystem degradation occur these being desertification in arid areas, increased woody plant cover in semi-arid/subtropical rangelands and deforestation in humid climates. Technical capacities exist to resolve the grazing livestock issue; however, the social and political implications of such solutions often impede implementation. For example, it is well known that successful utilization of arid grazing areas is dependent upon the ability to adjust animal numbers to climatic conditions and the ability to migrate from areas experiencing drought. Yet, producers find it difficult to destock at appropriate times, and movement to areas less

impacted by drought are difficult when dry season grazing areas are converted to crop agriculture and government policies restrict livestock movement.

Despite the array of negative environmental issues interfacing the livestock sector it is important to recognize that there are significant positive impacts which livestock have on the environment. Many examples have demonstrated how livestock can reduce chemical dependence for vegetation management - for example, in rubber production in South East Asia (Ismali and Thai, 1990) and in contolling noxious weed infestation in North America (de Haan *et al.*, 1997). In equillibrium

grazing systems no difference in erosion or water infiltration between light and moderately and ungrazed areas has been shown to exist (Blackburn *et al.*, 1982). Appropriately managed industrial systems can result in lower methane production (FAO, 2007) via increased efficiency, and concentration of livestock can lead to more cost effective mitigation of livestock pollutants (de Hann *et al.*, 1997). These types of positive livestock-environment interactions should be capitalized upon when policies for the sector are being designed.

Changing Animal Genetic Resource Use

As a result of changes in livestock product demand and environmental pressures, there is a need to better assess breed performance and explore altering breed performance levels within and across production systems to meet the challenges previously discussed. Such an evaluation should be focused on the judicious use of AnGR. Threats to AnGR have been summarized and include changes in production systems, markets preferences and environments, natural catastrophes, genetic dilution due to exotic germplasm use, unstable policies from public and private sectors and limited funds for conservation activities (Rege and Gibson, 2003; FAO, 2007). A number of policy interventions have been suggested to alleviate these situations; however, these policy recommendations have not been implemented, for as Mendelsohn (2003) states "*the conservation community has not provided a clear statement of the benefits of conserving AnGR*". By including AnGR in national agricultural policies, an integration of AnGR conservation and livestock sector development can be forged. Such a balance would ensure that an array of genetic variation is available for future utilization while enabling the advancement of other livestock production strategies.

With the dynamics of a livestock revolution upon us, it is useful to explore how AnGR use could change and therefore what policies might need to be developed. An important element of the livestock revolution is that economic growth and income levels will increase. As incomes grow there is a high income elasticity of demand for meat and other livestock products (Delgado *et al.*, 1999). It is the combination of income growth and elasticity of demand that enables broader sections of the global

society to increase their consumption of livestock products.

Changing consumer demand

There are examples of how consumer affluence and awareness impacts AnGR use. Several European countries have established landscape management programs that either require or suggest that rare/minor breeds be utilized. Participation in such programs by breeders provides an opportunity to obtain additional revenues, offsetting the difference in production income. However, care must be taken with such programs to ensure they do not to foster unnecessary subsidies or impediments to trade. There is anecdotal evidence suggesting that consumer demand will eventually shift toward a more diverse set of genetic resources. Such a pattern has been reported for heritage turkey breeds in the US (Blackburn, 2006) and rare breeds of sheep in Brazil (Mariante, personal communication). This demand tends to be coupled with an interest in supporting local products and the utilization of livestock for landscape management. Consumption of local products tends to be limited by the consumers' perception of price and that these products are for use on special occasions (Amanor-Boadu, personal communication). Furthermore, such changes have only emerged during the last decade and the scope and depth of these markets are unclear. However, these trends suggest that having a broad array of genetic resources available for future use to meet consumer demands will be of benefit to livestock keepers. Figure 3 presents a conceptualization of this scenario where consumer utilization of genetic diversity goes through a bottleneck and then broadens out as income levels increase and consumer preferences change. In essence, market demands will slow and/or mitigate contractions in genetic diversity and potentially broaden the use of AnGR as incomes increase and cause a shift in consumer preferences. If such a scenario were to become more prevalent, the challenge would be one of positioning national livestock populations to capitalize on the situation. Steinfeld *et al.* (2006) has suggested that globally there is still going to be a decrease in animal genetic diversity. However, they do point out that with consumers demanding more livestock products those same consumers will be more interested in knowing and determining how their livestock products are produced which would support the concept of a shift in genetic resource use that is illustrated in figure 3.
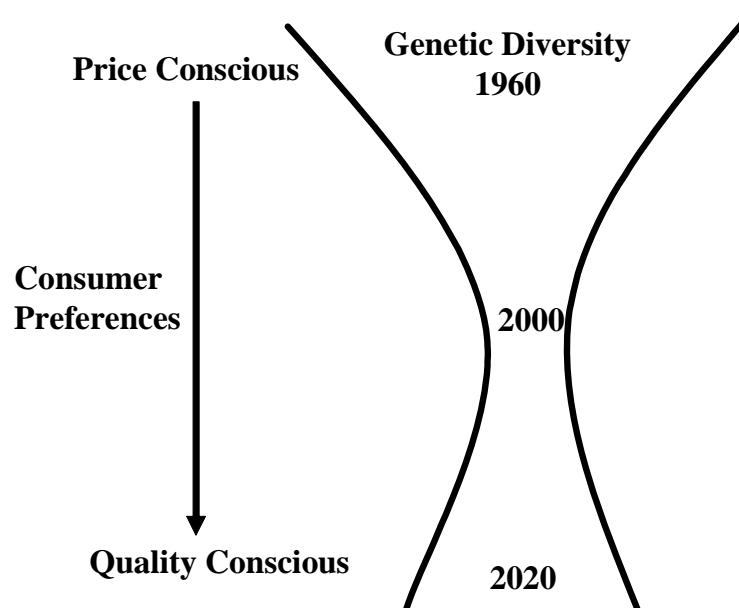
Figure 3. *Potential utilization of genetic diversity as income levels and consumer preferences change.*

Climate change

Global climate change is a potential driver for altering how AnGR may be used. If there is significant climate change it will most likely have the largest impact on ruminant species produced in extensive grazing systems, as those species and production systems are already subjected to relatively large environmental variations. Hanson *et al.* (1993) simulated an extensive grazing system in a short grass prairie under global climate change conditions of altered temperature, precipitation and increased CO_2 levels in northeastern Colorado (USA). Under all scenarios plant production increased but forage quality decreased. As a result weaning weights, cow weights and average daily gain decreased slightly. More importantly, variances for plant parameters increased suggesting that carrying capacities should be lowered by 36% to maintain a 90% confidence of not overstocking this rangeland. The potential for increased frequency of drought has also been discussed as a potential result of climate change, particularly for the African continent (FAO, 2007). Blackburn and Cartwright (1987) explored the impact of drought on varying genotypes and found that when genotypes are out of balance with the production system, a herd or flock's ability to recover from drought is compromised. Blackburn *et al.* (1990) extended this analysis and showed that smallholders are at greatest risk during such events and have less of a chance of recovering. Under such challenges balancing genotypes with production

systems will become a crucial element requiring the utilization of diverse genetic resources with appropriate genetic potentials for growth, milk production, resistance to disease and prolificacy.

Altering breed types is also an alternative response to climate change. Cundiff (2005) suggested a range of near optimal combinations of *Bos taurus* and *Bos indicus* inheritance as geographic locations changes within the USA (Gulf Coast, southern states and temperate regions). This situation can be observed in other countries having similar ranges of environments and genotypes that produce products for different markets (internal consumption, exportation to different and varied markets having specific demands in quality). For all such production systems, potential climate change could alter the suggested *Bos taurus* and *Bos indicus* combinations, resulting in new opportunities for AnGR use. Souza *et al.* (1998) underscored this point by demonstrating the presence of genetic-environmental interactions and subsequent changes in ranking across regions with Nellore cattle in Brazil. Under conditions of climate change such differences may be magnified. Madalena *et al.* (2002) discussed how poultry housing lacks environmental control in southern Asia, and therefore the need for local chicken breeds or varieties for industrial systems. The present use of such genotypes would suggest they would have greater importance under a global warming scenario. Kolmodin *et al.* (2002) showed how selection in the presence of genetic-environmental interaction may increase animals' environmental

. . . .

sensitivity. They also implied that animals could be selected for low sensitivity which could be an advantage in low input systems, or in the event of climate change. The work done by Misztal and Ravagnolo (2002) demonstrated how selection in Holsteins for heat resistance can be accomplished. All these reports suggest the reality of genetic-environmental interactions and the need to have genotypes that match the production environment in the event of a potential change in climate. Reports have also shown that selection for adaptability is possible; however, indigenous genotypes may already have a comparative advantage in the context of climate change, suggesting a need for within breed selection.

Genetic improvement

Genetic improvement activities in developing countries have had a checkered history (Madalena *et al.*, 2002). In part, genetic improvement among indigenous breeds for commercial traits is difficult due to the time required to achieve predetermined selection goals and therefore crossbreeding or breed substitution have been viewed as more expedient methods of increasing animal productivity. However, numerous reports detail the failure of various crossbreeding and breed substitution projects. Further complicating within breed improvement in developing environments is that single trait selection is not appropriate, and, when applied, genotypes may become unbalanced during periods of environmental instability (Blackburn and Cartwright, 1987). However, if multiple trait selection goals are clearly defined it may be possible to keep genetic combinations in balance during the selection process. This concept was simulated for pastoral sheep production in northern Kenya (Blackburn and Taylor, 1990), where selection for increased mature size and milk production was evaluated. These results indicated that culling age, which directly impacts selection intensity and genetic gain, was important in maintaining flock productivity. As culling age increased, flock productivity was higher than when culling age was decreased, resulting in a shorter generation interval. The need to retain animals longer to maintain production levels (which impacts generation interval) implies higher intensities of selection and therefore the need to closely monitor inbreeding levels.

Recent work by Gollin (personnel communication) suggests that indigenous genotypes (or those present in the production system for considerable time) may have a commanding advantage in terms of productivity and that there will not be significant migration of genetic resources from developing to developed countries. He found that under prevailing market conditions and existing levels of productivity with the current set of breeds, that imported breeds from developing countries have little opportunity to become mainstreamed, making successful new breed importation difficult to achieve. This result draws into question the hypothesis of Gibson and Pullin (2005) that there would be increased demand for genotypes from developing countries.

General Agriculture Policy Goals

National agricultural policies are developed principally to promote economic growth and food security. In setting national policies there is an international consensus that direct government interventions in the economy generally should be reduced along with fiscal expenditures (Norton, 2004). Norton further explains that at the producer level, agricultural policies should fulfill three basic needs: incentives to produce (not to be confused with subsidized production), a secure resource base, and access to markets for outputs and inputs, including technology.

AnGR conservation management intersects these three basic needs and therefore policies concerning AnGR can be structured within each of the three areas. However, complicating the development of AnGR policies is the lack of assessment and valuation methodology for AnGR in the context of food security and economic growth. Clearly, AnGR can contribute to economic growth and food security, but the level of contribution has not been quantified in any substantial way, underscoring Mendelsohn's (2003) view. In general, we do know that the livestock species domesticated by man in the last 12 000 years contribute directly or indirectly to 30 to 40% of the total value of food or agriculture production at a global level (FAO, 2000). But such assessments at the breed level are missing.

Policy Framework for Animal Genetic Resources

Potential policies range from broad to specific policy instruments that are targeted directly at

. . . .

AnGR, livestock-environmental interactions, and livestock sector development. The framework discussed strives to promote all three elements through the areas of incentives to produce, a secure resource base, and access to markets for outputs and inputs. Madalena *et al*. (2002) stated the major issues depressing effective breeding and AnGR utilization are excessive bureaucratic constraints and the need for producer driven programs. They also suggest that breeding programs are not likely to "*succeed if the program is focused upon grandiose schemes, are run by government or international agencies, or are driven by policy goals with few benefits to participants*". In other words, breeding and AnGR utilization are private sector activities where government, international agencies and non-governmental organizations should play secondary or supportive roles. This perspective confirms the points made by Norton (2004).

Given the issues of AnGR addressed by Madalena *et al*. (2002) and the fact that AnGR are contracting, there is a need for policies to manage AnGR that consider the performance of past efforts and the realities of the challenges in meeting the demands of the livestock revolution. Given the practical considerations of Madalena *et al*. (2002), effective policy formulation is also inhibited by the need for determining the long term value of AnGR (Mendelsohn, 2003). Gollin and Evenson (2003) point out three primary sources of value - direct use, indirect use, and non-use - which can serve as approaches to establish the quantitative worth of AnGR. Studies articulating the value of AnGR using one of these three valuation approaches are necessary to firmly establish effective long-term policies. It is key in developing methods for valuing AnGR that not only market value but other traits like adaptation to local environment or disease resistance, which in fact also determine the value of the resource be considered (de Haan *et al*. 1997; Rege and Gibson, 2003). Kanis *et al*. (2005) proposed a method based on selection index theory which incorporates socially important traits such as animal welfare and health, which can be selection goals but have no direct economic value. Such an approach could be applied on a community basis where genetic resources must be well matched to the production environment because AnGR are used as a food source, for traction, and/or manure. For these situations, the establishment of programs of participatory breeding with the owners or stakeholders of the AnGR is appropriate and must be factored into policy making for managing and conserving AnGR in conjunction with environmental and economic issues.

Incentives to Produce

In many production systems producers have or are moving away from indigenous or minor breeds to take advantage of specific production traits (SOW, 2006). However, globally this type of breed substitution has been shown to be problematic, particularly among the ruminant species which are expected to produce in a new environment with little or no genetic or managerial modification. In most situations the new breed may be shown to be superior for a trait of interest (e.g., milk production, growth rate, disease resistance), but when evaluated on the basis of biological efficiency or life time productivity, the new breed often ranks below the breed already being utilized (Blackburn, 1995; Blackburn *et al*., 1998). The mixed history of breed introductions suggests that prior to wide spread dissemination, multi-year breed comparisons be performed to better ascertain a breed's potential in the new production system (de Haan *et al*., 1997). Having such an analysis will make more evident the managerial changes necessary for some breed types to be effectively used and can be extended into cost/benefit analyses. The result of this effort should improve the decision making by breeders contemplating the use of new breed types and could encourage them to employ appropriate selection strategies.

In certain situations policies could be developed that encourage utilization of some breeds in conjunction with land conservation strategies. Such policies have been implemented in several European countries (FAO, 2007). There are additional opportunities to merge AnGR conservation efforts with landscape or vegetative management strategies. In such situations policies could specifically call for the utilization of rare and/or minor breeds. Furthermore, where vegetation is being controlled on public lands, access could be restricted to the use of rare and/or minor breeds. Such an approach would accomplish the land management goal and AnGR conservation without a cash subsidy but may create concern about producer equity. Where private lands are concerned the issue of payment has to be addressed and whether society deems such an effort important enough to make a public investment without distorting markets. Presently, it would appear that once a country's economy reaches a sufficient level and consumer preferences change, as illustrated in figure 3, policies permitting direct subsidy payments may no longer be necessary. Perhaps the major issue with such strategies is whether or not sufficient scale in land mass and animal numbers

can be achieved to promote *in-situ*/*in-vivo* conservation of a large number of breeds. Some regions have implemented subsidies for maintaining breeds of interest based upon animal numbers (FAO, 2007) however, it would appear that such approaches invite producers to maintain numbers below minimum threshold levels to continue to receive the subsidy and therefore limit the growth and utilization of a breed.

A Secure Genetic Resource Base

From a policy and technical standpoint the first and most significant step in securing AnGR is the development and implementation of a national database/information system. The development of this capacity enables policy makers, scientists, and industry to understand the country's AnGR through trend analysis of population demographics, geographic location, phenotypic and genotypic information, and ownership patterns. It also serves to document the utilization of various breeds. In addition, development of national databases is the first step in developing an understanding of the status of breeds that are shared between countries within a region.

The second policy step to secure the AnGR base is the country's decision to develop *ex-situ*/*in-vivo*, or *ex-situ*/cryopreserved collections of germplasm and/or tissue. The decision for *ex-situ*/*in-vivo* collections, *ex-situ*/cryopreserved collections or both is primarily a financial consideration (Gollin and Evenson, 2003) to the extent that the two are substitutes. It would appear that limited financial and physical resources will control the number of *ex-situ*/*in-vivo* populations that can be maintained and therefore *ex-situ*/cryopreserved collections will, in the long run, be a more flexible, cost effective, and sustainable approach for conserving AnGR. Such collections can serve multiple functions, for example: a secure reserve of germplasm for population regeneration; a source of genes that may potentially become lost due to selection pressure; a source of genes that assists breeders in modifying their populations to better meet consumer demand; and, a source of DNA for the research community. By increasing the scope of collection utilization the costs of collection development and maintenance are reduced. Furthermore, re-sampling can be performed to ensure that collections represent the populations at any point in time. Issues of collection redundancy can be addressed within a country, regionally or even on a global scale (although this is logistically more complex). On the other hand, when funds are not limited, maintaining *ex-situ/in-vivo* populations have the advantage that populations can adapt to changing environments, production systems or markets. In addition, the population can be seen by farmers which in turn could facilitate actions to promote breed utilization.

Access to Markets for Outputs and Inputs, including Technology

In order to facilitate national livestock sector economic growth potentials, and therefore allow countries to participate in the livestock revolution (Delgado *et al.*, 1999), rare and minor breed types will be under continued economic pressure (Mendelsohn, 2003; FAO, 2007). However, their position can be enhanced by eliminating the sources of market failure which Wollny (2003) cites as one reason for diversity loss. The positive benefits of establishing dynamic and well functioning markets, and their role in conservation and development, has been documented in the well studied Machakos District in Kenya. In this area market access made small scale dairying possible which in turn generated capital for investments in soil and water conservation (Tiffen *et al.*, 1994).

Some authors have suggested trade restrictions be put in place to reduce or eliminate the importation of exotic germplasm. However, as Norton (2004) notes, "*there is an international consensus that high rates of protection not only invite retaliatory protection measures but also lead to inefficiencies in a country's own production structure, by removing the pressure for productivity increases and for reallocating a country's productive resources to its more competitive product lines*". Given this insight, several steps are required to overcome the shortcomings of the market place. There should be an elimination of import and export subsidies to encourage the breeder-driven market place to determine the appropriateness of indigenous or exotic breeds. Better market information concerning the value of various genetic resources is required. Markets should be open allowing a free flow of germplasm so there will be greater opportunities to increase the utilization of genetic diversity, particularly as consumer demand shifts to regionally-produced products (de Haan, *et al.*, 1997).

Access to technology/information also provides an opportunity to correct market failures. As mentioned previously, correcting the manner in which breeds are evaluated should provide all

livestock producers with a much clearer perspective on how breeds will perform in a given production system. There is also a need to employ other technologies such as assisted reproductive technologies. Some of these technologies have become routine and require much less technical training than once perceived. Given past experiences (Madalena *et al.*, 2002), there is a significant need to blend the utilization of various technologies with local breeding expertise. A component of such a policy could be the strengthening of breeding organizations where breeders reach a consensus on AnGR use and the breeding strategies necessary to achieve economic growth. If a country does determine it beneficial to establish *ex-situ*/cryopreserved collections there will be a need for varying degrees of training. Furthermore, by taking this approach the country allows breeders an effective mechanism to make use of specific AnGR and create new marketing opportunities.

Policies integrating Conservation, Demand, and Environment

There are policies by which the nexus of AnGR, environmental concerns, and consumer demand can be addressed and fit within the framework described. One such policy is the establishment of clear title to land ownership or use. Land title cuts across the areas of incentives to produce and provides livestock producers with a secure resource base from which to produce livestock. Furthermore, it promotes a balance between the production potential of livestock (and thereby genotypes) and the environmental capacity of their resource. It will permit owners of grazing based livestock to match land use with ecological processes so as to exploit the temporal and spatial variation of key resources and therefore promote opportunities for both livestock production and wildlife. Knowledge of the resource capacity also allows producers to better match genotypes to specific environments, and in determining if new genotypes are to be introduced what type of external inputs are needed to achieve success.

Elimination of market distortions, such as under-valued prices on breed importation schemes, is also a cross-cutting policy affecting livestock producers' incentive to produce and maintain indigenous genetic resources, improved market access for inputs and outputs and the mitigation of

negative impacts of the environment. Elimination of subsidies or distorted prices on genetic resources will level the playing field for all breed types. Without such influences breeders should be in a better position to evaluate the ramifications of utilizing existing genetic resources or modifying their populations through within breed selection, crossbreeding, or breed substitution.

Improving market structures to provide producers with access to inputs, outputs and new technologies is also important. This includes the prospect of access to international exchange and utilization of animal genetic resources. Providing breeders/livestock keepers with access and stable markets allows them the opportunity to search for and evaluate potentially beneficial genetic resources, thereby responding to increased consumer demand, intensifying production, and lowering environmental impacts. In addition, having secured market channels has been deemed a necessary element for adjusting extensive grazing system stocking rates during times of drought.

Conserving AnGR should not be considered juxtaposed to the implementation of new technologies that can promote intensification. Through appropriate intensification there will be reductions of resource use and waste emissions across the board (Steinfeld *et al.*, 2006). Furthermore, livestock products can be tailored to various consumer groups as part of the intensification process. But for appropriate technologies to emerge, national research organizations must be strengthened and public-private linkages must be fostered and enhanced.

Economic and environmental pressures to utilize alternative AnGR will continue and producers are likely to shift to such AnGR, where they deem appropriate. As a result, developing *ex-situ*/cryopreserved stores of genetic resources may need to become a primary mechanism for conserving diversity. By building such *ex-situ*/cryopreserved collections producers have the opportunity to adjust breeding stock to meet the realities of the livestock revolution, while being assured that AnGR used in the past are secure and available for future use if needed. This type of public facilitation role fits well with concepts discussed earlier in this paper (Norton, 2004; Madalena *et al.*, 2002). It has often been suggested that infrastructure and human capacity are lacking to put such repositories in place and that they are more costly than *in-situ* conservation. However, no comprehensive comparison has been performed. It could well be that *ex-situ*/cryopreservation collections have high initial investment costs but

lower recurrent costs, when compared to *in-situ* conservation. Furthermore, globally a number of within country capacities exist and with little additional effort resources can be brought to bear for implementing this type of conservation program.

Conclusion

Global demand for livestock products, the need to mitigate environmental degradation and national economic growth agendas requires maximum use of AnGR. Yet after one decade of becoming aware of the growing consumer demand, it appears that supply is not keeping pace. In addition, long term livestock - environmental issues (e.g., resource degradation due to grazing) remain unresolved. Increased productivity will require the utilization of more commercialized, higher-producing AnGR that will in turn create more short term pressure on AnGR diversity. Furthermore, the literature suggests that by increasing animal productivity, which may require the utilization of new breeds or intensive selection within indigenous breeds, negative environmental impacts can be mitigated. Considering these pressures breeders will have to capitalize on indigenous breed adaptability while selecting for traits that meet consumer demands for indigenous AnGR to be competitive. As a result of the convergence of the major issues discussed in this paper, policies concerning AnGR should be put in the context of three categories: incentives to produce, securing the resource base, and providing access to markets for inputs and outputs. In making these assignments, potential policies also need to consider the impact they may have on the environment. To meet the current economic, environmental and conservation challenges there is perhaps a need to assess productivity from another perspective, such as life-time productivity and ability to withstand environmental stressors (e.g., drought and disease). There are significant informational needs (e.g., phenotypic/genotypic descriptors, database development, status of breeder capacity) all of which contribute to making more informed choices concerning genetic resource use, as well as solving livestock product demand and environmental issues.

While some have advocated restrictive trade policies as a mechanism to protect indigenous genetic resources, the body of literature on trade indicates that such approaches are not conducive to economic growth and development. Such practices impede the opportunity to encourage producers in other countries to evaluate and utilize the AnGR in question. In addition to trade restrictions, there has also been a call for so-called access and benefit sharing agreements, the benefits of which are unknown. But, if perceived discrepancies exist between buyer and seller, these are without question a failure of market information and should be resolved by correcting marketing issues and information flow rather than imposing more restrictive policies that will harm the livestock sector's growth. In summary, advancement of policies for AnGR will require a clear statement of the value of AnGR, policies that support breeders in making informed choices about the use of AnGR, development of *ex-situ*/cryopreserved germplasm collections and placing AnGR policies in the context of larger national agendas that address economic growth, consumer demand and environmental sustainability.

Acknowledgments

List of References

Asner, G. P., A. Elmore, L. Olander, R. Martin & A. Harris. 2004. Grazing systems, ecosystem responses, and global change. Annual Review of Environment and Resources. 29: 261-299.

Blackburn, H.D. & T.C. Cartwright. 1987. Simulated genotype, environment and interaction effects on performance characters of sheep. J. Anim. Sci. 65: 399-408.

Blackburn, H.D., K. Zessin, J.F. Taylor, T.C. Cartwright & B.A. Mwandotto. 1990. Flock dynamics during drought and recovery years. Proc. 8th SR-CRSP Scientific Workshop. Nairobi, pp. 15-28.

Blackburn, H.D & J.F. Taylor. 1990. Simulation of flock performance when different intensities of selection are practiced. 4th WCGALP. 15: 127-130.

Blackburn, H. 1995. Comparison of performance of Boer and Spanish Goats in two U.S. locations. J. Anim. Sci. 73: 302-309.

· ·

Blackburn, H., S. Lebbie & A. van der Zijpp. 1998. Animal genetic resources and sustainable development. 6th WCGALP. 28: 3-10.

Blackburn, H. 2006. The National Animal Germplasm Program: Challenges and opportunities for poultry genetic resources. Poultry Sci. 85: 210-215.

Blackburn, W.H., R. Knight & M. Wood. 1982. Impact of Grazing on Watersheds; A State of Knowledge. Texas Agric. Exp. Sta. MP 1496, pp. 32.

Cundiff, C.V. 2005. Tropically adapted breeds – Regional Project S-1013. Southern Cooperative Series Bulletin, pp. 131-143.

de Haan, C., H. Steinfeld & H. Blackburn. 1997. Livestock and the Environment: Finding a Balance. WREN media, Suffolk, UK, pp. 115.

Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui & C. Courbois. 1999. Food, Agriculture, and the Environment Discussion Paper 28. Int'l. Food Policy Res. Inst., pp. 72.

FAO. 2000. World Watch List for Domestic Animal Diversity, 3rd. Edition, FAO, Rome, Italy.

FAO. 2007. The State of the World's Animal Genetic Resources for Food and Agriculture. FAO, Rome, Italy.

Gollin, D. & R. Evenson. 2003. Valuing animal genetic resources: lessons from plant genetic resources. Ecological Economics. 45: 353-364.

Gibson, J. & R. Pullin. 2005. Conservation of livestock and fish genetic resources: joint report of two studies commissioned by the CGIAR Sceince Council. Science Council Secretariat. (*www.sciencecouncil.cgiar.org/activities/spps/pubs/ AnFiGR%20study%20report.pdf*).

Hanson, J. D., B.B. Baker & R.M. Bourdon. 1993. Comparison of the effects of different climate change scenarios on rangeland livestock production. Agric. Systems, 41: 487-502.

Ismali, T. & C.D. Thai. 1990. Report on the Small Ruminant Collaborative Research Support Project (SR-CRSP) Indonesia Workshop. US Agency for International Development, Washington, DC.

Kanis, E., K. De Greef, A. Hiemstra & J. van Arendonk. 2005. Breeding for societally important traits in pigs. J. Anim. Sci. 83: 948-957.

Kolmodin, R., E. Strandberg, H. Jorjani & B. Danell. 2002. Selection in presence of genotype by environment interaction may increase environmental sensitivity. 7th WCGALP. 32: 333-336.

Leng, R.A. 1991. Improving Ruminant Production and Reducing Methane Emissions from Ruminants by Strategic Supplimentation. U. S. Environmental Protection Agency, Washington, D.C. EPA/400/1-91/004.

Madalena, F., K. Agyemang, R. Cardellino & G. Jain. 2002. Genetic improvement in medium- to low-input systems of animal production. Experiences to date. 7th WCGALP. 33: 331-340.

Mendelsohn, R. 2003. The challenge of conserving indigenous domesticated animals. Ecological Economics. 45: 501-510.

Misztal, I. & O. Ravagnolo. 2002. Studies on genetics of heat tolerante in Holsteins. 7th WCGALP. 32: 345-348.

Norton, R. 2004. Agriculture Development Policy: Concepts and Experiences. FAO, Rome.

Rege, J. & J. Gibson. 2003. Animal genetic resources and economic development: issues in relation to economic valuation. Ecological Economics. 45: 319-330.

Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales & C. de Haan. 2006. Livestock's long shadow: environmental issues and options. FAO, Rome, Italy.

Souza, J., A. Ramos, A. Silva, K. Euclides Filho, M. Alenctar, F. Wechsler, C. Gadini & L. Van Vleck. 1998. Effect of genotype x environment interaction on weaning weight of Nelore calves raised in tour different regions of Brazil. 6th WCGALP. 23: 193-196.

Tiffen, M., M. Mortimore & F. Gichuki. 1994. More People, Less Erosion: Environmental Recovery in Kenya. John Wiley & Sons, Chichester, UK.

Wollny, C. 2003. The need to conserve farm animal genetic resources in Africa: should policy makers be concerned? Ecological Economics. 45: 341-352.

· ·