

Impacts of Climate Change on Livestock Genetic Diversity and Selection

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Introduction

Livestock production both contributes to and is affected by climate change (FAO (2010)). In addition to the physiological effects of higher temperatures on individual animals, the consequences of climate change are likely to include increased risk that geographically concentrated rare breed populations will be affected by disturbances. The IPCC predicts an increase in disturbance and catastrophic weather events. Loss of animals as a result of droughts and floods, or disease epidemics related to climate change may thus increase. If breeds are geographically isolated – as is the case for some local and rare breeds – there is a risk of their being lost in localized disasters (Carson *et al.* (2009)). Indirect effects may be felt via ecosystem changes that alter the distribution of animal diseases or the supply of feed. Breeding goals may have to be adjusted to account for higher temperatures, lower quality diets and greater disease challenge.

Bio-geographic projections of climate change impacts for livestock breeds are complicated: Firstly, several species were domesticated in the same region, implying that they have similar environmental envelopes. Secondly today, many breeds of the major livestock species are globally distributed, implying that the geographic distribution of specific breeds is overlaid by different production systems. In addition, detailed data on most breeds' adaptation traits, including their thermal neutral zones and spatial distribution, are not available. Consequently, bio-geographic models or breed-level predictions of the implications of climate change on livestock diversity are hardly possible with current data (Hoffmann, 2010).

The global livestock sector is characterized by a growing dichotomy between livestock kept by large numbers of smallholders and pastoralists for livelihoods and rural food security, and those kept in intensive commercial production systems. FAO's latest global assessment of breed diversity identifies 7040 local breeds (each reported by only one country) and 1051 transboundary breeds (each reported by several countries) (FAO (2009)). About two-thirds of reported breeds are currently found in developing countries. Local breeds are commonly used in grassland-based pastoral and small-scale mixed crop-livestock systems where they deliver a wide range of products and services to the local community, with low to medium use of external inputs. They are usually not well characterized and described and seldom subject to structured breeding programmes to improve performance. So-called "international transboundary breeds" of the five major livestock species (cattle, sheep, goats, pigs, chickens), many of them high-output commercial breeds, have spread globally for use in

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large-scale, often landless, market-oriented production systems with high levels of external inputs. Industrial systems utilizing sophisticated technology and based on internationally sourced feed and animal genetics already produce 55% of pork, 68% of eggs and 74% of poultry meat globally (Steinfeld *et al.* (2006)).

Genetic mechanisms influence fitness and adaptation. Adaptation traits are usually characterized by low heritability; however, they are expected to respond to selection if the environment shifts, resulting in change of fitness profiles and increase in heterozygosity.

Impact of climate change on individual animals

Heat stress is an important factor in determining specific production environments already today, impacting male and female reproduction and production and increasing mortality. It is predicted to increase globally, with reduced precipitation in many regions, particularly in already arid regions. Measurement of the effects of heat and other stressors is complex and difficult. Heat stress alters the animals'. Although the direct effects of climate change on the animals are likely to be small as long as temperature increases do not exceed 3° C, climate change will affect animals directly through physiological stress and thermoregulatory control, nutrition and disease stress.

Hoffmann (2010) reviews species and breed differences in reaction to these stressors. Substantial differences in thermal tolerance lie between species; however, there are also differences between breeds of a species. Ruminants generally have a higher degree of thermal tolerance than monogastric species, but species and breed environmental envelopes overlap. *Bos indicus* is generally more heat resistant than *Bos Taurus*. In general, the high-output breeds originating from temperate regions that provide the bulk of market production today are not well adapted to heat stress, partly because of increased metabolic heat production. Breed and species differences in nutrient requirements and feeding behaviours (e.g. diet selection) have been observed linked to different metabolic profiles. There are also breed differences in disease resistance that may become relevant to buffer against the projected rapid spread of pathogens or even small spatial or seasonal changes in disease distribution. The expected increased and often novel disease pressure will favour genotypes that are resistant or tolerant to the diseases in question

Adaptation to harsh environments includes not only heat tolerance but also to their ability to survive, grow and reproduce in the presence of poor seasonal nutrition as well as parasites and diseases. In general, research in these various aspects of adaptation has been conducted with few species and breeds - mostly international transboundary breeds - and mostly in controlled production systems. There are knowledge gaps in the reaction norms and physiological mechanisms of many local breeds and in extensive grazing systems. FAO (2007a; 2006) list many species and local breeds which are already adapted to high temperatures and harsh conditions, or are reported to be resistant or tolerant to various diseases. Many of these reports are based on anecdotal evidence rather than scientific studies, and the underlying physiological and genetic mechanisms are not well understood. This makes it difficult to predict climate change impacts or develop adaptation strategies for such production systems or breeds.

Adaptation to climate change

There are many ways in which livestock keepers can adapt to climate change. They can adapt their animals' genetics to the changed environment, or adapt the production environment while maintaining their breeds. Usually, livestock keepers will first use adaptation technologies that can be quickly deployed, and will only change their species and breeds when it becomes unavoidable.

Conservation

Conservation aims to maintain the option value of genetic diversity, it is therefore a priority of the Global Plan of Action for Animal Genetic Resources (FAO (2007b)). Conservation measures for threatened breeds have already been established in some countries (FAO (2007a)). Most current conservation programmes are based in developed countries with strong collaboration between gene banks and animal breeding organizations (FAO (2007a)). In developing countries, the focus is typically on in vivo conservation. Few breeds of the five major species are covered by conservation programmes, and programmes are of variable quality (FAO (2007a)). Conservation usually involves the characterization of animal genetic resources and the subsequent development of inventories, including information on the spatial distribution of breeds and valuable breeding stocks, and priority setting (Boettcher et al., 2010; Joost et al., 2010).

With climate change and the predicted increase in disturbances and disasters, the focus may shift from in vivo to in vitro conservation of animal genetic resources. The sensitivity of in situ conservation programmes to the effects of climate change should be assessed and ex situ conservation measures be taken if needed. Therefore, after the development of inventories and early warning systems, conservation may involve the establishment of gene banks for local breeds and backups for commercial breeds.

Breeding

Breeding and selection aim to improve the use value of animal genetic diversity. Climate change projections suggest that further selection for breeds with effective thermoregulatory control may be needed. Breeding for climate change adaptation or mitigation will not be fundamentally different from existing breeding programmes; however, the problems related to measuring the phenotypes relevant to adaptation have to be overcome. Breeding indices should include traits associated with thermal tolerance, low quality feed and disease resistance, and give more consideration of genotype-by-environment interactions (GxE) to identify animals most adapted to specific conditions (see Hoffmann (2010) for details).

Different parameters (e.g. temperature-humidity index or dry-bulb temperature measurements) are used as indicators for heat stress in genetic evaluation models. The genetic variance due to heat stress is substantial (Ravagnolo & Misztal (2002)), therefore

selecting for heat-resistant individuals can be a strategy to improve animal welfare and productivity in hot climates. Various physiological (e.g. the ability to maintain lower rectal temperatures) and blood parameters differ between local and exotic cattle breeds (McManus *et al.* (2008)), and research in the major “slick hair” gene which is dominant in inheritance and located on Bovine Chromosome 20 is ongoing (Dikmen *et al.* (2008)). However, genetic antagonisms between heat tolerance, milk yield and reproductive performance indicate that it may be difficult to combine the traits desirable for adaptation to high temperature environments with high production potential in the dairy sector (Ravagnolo & Misztal (2002)). Such genetic antagonisms between adaptation to high temperature environments and high production potential seem to be less prominent in beef cattle where improved characterization of adaptive traits, use of reproductive technologies and molecular markers, and strategic crossbreeding are being used in breeding programmes.

Most breeding related to feeding is related to increasing productivity and feed efficiency of high-output breeds rather than enabling animals to better deal with low quality feeds. This aims to reduce enteric methane emissions from the sector. Breeding has significantly reduced the amount of feed (and land needed to produce this feed) per unit of product – more in monogastrics and in dairy cattle than in beef cattle or sheep. This is due to increased performance, improved FCR and reduced mortality – often due to better hygienic management. Currently, research in host components of rumen function, in genetic variation in digestion parameters in post-absorption nutrient utilization and in disease resistance is ongoing.

There is a potential for fertility improvements in ruminants – for example decreasing the age of first-calving in zebuine cattle. Sufficient genetic variability in feed intake permits selection for this trait in addition to higher heat stress tolerance (Hayes *et al.* 2009)). Feed-efficient animals are also more cost-effective and productive, therefore net feed efficiency can be used as an integral part of breeding programmes. However, initial costs to identify individuals with low residual feed intake are high, particularly in grazing animals (Arthur *et al.* (2004)). Because feed quality in tropical pastures is lower than in temperate pastures, productivity improvements in grazing ruminants in the tropics will result in higher relative methane reductions than in ruminants grazing temperate pastures.

Disease resistance depends very much on the type of pathogen and the hosts’ resistance or tolerance mechanisms. Breeding for disease resistance is influenced by the availability and costs of alternative treatment (e.g. vaccines, drugs) and antimicrobial resistance of pathogens. Potential exists for genetic improvement of disease resistance, and various commercial breeding programmes already include resistance against helminthosis, ticks, mastitis, *E. coli* or scrapie. Many of these programmes depend on the use of molecular markers and marker assisted selection.

Interdependence

Most countries are highly interdependent with respect to animal genetic resources as their livestock production depends on species and breeds originally domesticated elsewhere (FAO (2007a, b)). Climate change and future food security needs may increase this

interdependence and the need to maintain wide access to animal genetic resources. However, breed transfer between countries has been only successful if based on a combination of several desired production traits and the interest and acceptance of the livestock sector. In the past decades, many developing countries have imported genetic progress in production traits rather than developing it in their local breeds (FAO (2007a)).

Currently, selection for improved adaptation takes place within the high-output breeds, with multi-trait selection indices – and genomic selection will make even better use of the genetic variation present in the commercial populations. Crossing or introgression of adapted genes local breeds from developing countries is not used to increase adaptation in commercial populations because the differences in production performance. Therefore, it remains to be seen whether the impact of climate change will lead to an improved recognition and use of the adaptive traits harboured by local breeds. In any case, only well-characterized breeds will be used for targeted crossing or gene insertion to increase the adaptedness of high-output breeds. However, most developing countries have insufficient resources or capacity for genetic or phenotypic breed characterization or breeding programmes, and very few countries have commercially relevant tropically adapted breeds (FAO (2007a)). Therefore, it is difficult to improve characterization and selection within local breeds from developing countries for both, increased production and improved adaptation. It remains to be seen whether genomic selection will exacerbate these trends or provide developing countries with simple tools for breeding (Hoffmann (2010)).

Countries would only depend on better-adapted genetic resources from other countries to adapt their food and agriculture systems if climate change will exceed the adaptive capacity of the currently used breeds. In this case, the importance and value of specific genetics would increase, and tropically adapted breeds may become interesting also for temperate developing countries. In the interest of global food security, it would then be crucial to maintain wide access to genetic resources through improved exchange mechanisms.

Conclusion

The livestock sector is highly dynamic, and climate change will be an additional factor affecting this dynamics (FAO (2010)). However, due to more pressing current needs and climate change's slow but long-term effect, the livestock community is not yet fully aware of its possible impact on the sector. The direct effects of climate change will depend very much on the livestock production and housing system, with high-output breeds in confined systems being better protected from natural adversities than breeds in extensive grazing systems. The need for increased production efficiency while reducing the environmental footprint of livestock will continue to be major future challenges. Climate change will increase the need for resource-efficient livestock production and may thus intensify current trends with a growing dichotomy between livestock kept in extensive and those in intensive systems. The possible social implications are beyond the scope of this paper.

At current state of knowledge, it is not predictable whether climate change will be faster than natural or artificial selection. It would be an interesting research question to assess and model the likelihood, speed and impact of the various aspects of climate against genetic evolution

of livestock and use the results to guide the need for interventions. Developed and developing countries differ with regard to the genetic resources they harbour and the management of these resources. Most high-output breeds are selected for the requirements of developed country markets and production systems. On the other hand, most tropically adapted breeds reside in developing countries and are largely uncharacterized and without structured breeding or conservation programmes. Local breeds are key resources in the livelihoods of rural people. In view of the uncertainty for future developments and climate change, the use and non-use values of animal genetic resources should be maintained. Research has an important role to play in this regard. Immediate needs are to:

- develop simple methods to characterize adaptive traits and better characterize, evaluate and document adaptive and performance traits in specific production environments (FAO, 2008b), including the associated knowledge;
- improve methods to assess the use and non-use values of animal genetic resources;
- inventory breeds including relevant spatial information, and monitor threats to breeds, be they caused by climate change or other drivers (e.g. geneflow). This may entail some basic predictive modelling of future breed distribution and early-warning systems;
- strengthen conservation systems. While in situ conservation is favourable due to its pro-poor effects, ex situ conservation programmes need to be developed to cater for habitat destruction and allow for emergency response;
- improve adaptive traits in high-output and performance traits in adapted breeds, and support developing countries in their management of animal genetic resources;
- develop methods for live-cycle assessments and include delivery of ecosystem services in the analysis, and recognize and reward C-sequestration and sustainable use of biodiversity in well managed rangelands with local breeds; and
- facilitate wide access to genetic resources and enable transparent exchange of the associated knowledge in local and commercial breeds.

Without support in breed characterization, breed improvement and conservation for developing countries, the scientific divide will continue to increase (OECD-FAO (2009)) and developing countries may lose once again. The long-term commitment required for genetic improvement and the easy imports of high-output genetic material may discourage developing countries from initiating their own breeding programmes. However, for the optimal utilization of the adaptation traits harboured in all breeds, research in genetic characterization and understanding adaptation in stressful environments needs to be strengthened. Agro-ecosystem modelling may be a useful tool to improve our understanding about the complex interaction between livestock genetics and adaptation with changes in the biophysical and socio-economic environment.

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