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CLIMATE CHANGE AND ANIMAL GENETIC RESOURCES FOR FOOD AND AGRICULTURE: STATE OF KNOWLEDGE, RISKS AND OPPORTUNITIES

by

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ABSTRACT

The objective of this background study paper is to describe the implications of climate change for the management of animal genetic resources for food and agriculture (AnGR). Specifically, the focus is on the genetic resources of domesticated avian and mammalian species that contribute to food production and agriculture.

Climate change comes as an additional factor affecting a livestock sector that is already highly dynamic and facing many challenges. Important objectives of AnGR management include ensuring that AnGR are effectively deployed to meet these challenges (i.e. are well matched to the production environments in which they are kept) and that the genetic diversity needed to adapt production systems to future changes is maintained. Climate change is likely to create a number of problems in many areas of animal husbandry (housing, feeding, health care, etc.) and threaten the sustainability of many livestock production systems and their associated AnGR. At the same time, many of the specific challenges associated with climate change (high temperatures, disruptions to feed supplies, disease outbreaks, etc,) as well as the general unpredictability it brings to the future of the livestock sector, highlight the importance of retaining diverse genetic options for the future.

Climate change is predicted to lead to a rise in temperatures globally. In parts of the world it is likely that this will increase the problem of heat stress in livestock and require adjustments to husbandry and production strategies. Although the high-output breeds that increasingly dominate global livestock production are usually not well adapted to heat stress, the high external input systems in which they are often kept provide several options for alleviating the effects of high temperatures, including the use of cooling systems (sprays, etc.) and adjusting the diet to reduce metabolic heat production. Such production systems are generally quite well able to protect animals from the local-scale effects of climate change. However, their heavy reliance on external inputs may make them vulnerable to rising prices – a problem that may be exacerbated by climate change. In production systems where heavy use of external inputs is not possible, the importance of well adapted animals is likely to increase under climate change.

Climate change is likely to lead to changes in disease epidemiology. Precise effects are difficult to predict, but combined with problems in the sustainability of some conventional disease control methods, climate change-related effects are likely to increase the importance of genetic resistance and tolerance in disease control strategies. Changes in the distribution and incidence of diseases that kill large numbers of animal or induce culling measures for disease control may pose additional threats to AnGR diversity, but precise effects are again difficult to predict.

Climate change is likely to affect the availability of feed resources within land-based production systems, in some cases threatening their sustainability. "Industrial" producers can adapt to the local scale effects of climate change on feed supply by drawing on world feed markets, but are again potentially vulnerable to the effects of climate change on prices.

Traditional production systems tend to have the advantage of keeping animals that are well adapted to harsh conditions and that can thrive without the use of expensive inputs. In many such systems, the livestock keepers are also experienced in dealing with extreme and fluctuating environmental conditions. Nonetheless, their reliance on local natural resources makes them vulnerable to problems such as declining availability of forage or the emergence of unfamiliar diseases or parasites. Traditional systems are often already under a variety of pressures, many of which may be exacerbated by climate change. Many livestock keepers are poor and lack the financial and other livelihood resources that could help them in adapting to climate change. Production systems in which non-locally adapted livestock have been introduced without the accompanying developments needed to support such animals, or where the supply of external inputs is precarious, may be vulnerable to many of the direct and indirect effects of climate change.

Although there are potential means in which the sustainable use of AnGR can be integrated within climate change mitigation strategies, it is also possible that such strategies could pose a threat to AnGR diversity, particularly if they are hostile to grazing and other traditional production systems that are deemed "inefficient".

The speed of climate change may outstrip the ability of AnGR to adapt genetically or that of their keepers to adjust their management strategies. In places, this may break the link of adaptation between local livestock and their production environments. If such effects occur, adapting production systems and AnGR management will be a major challenge and may increase the need for moving AnGR into new areas and for quickly adjusting breeding objectives.

The genetic diversity of the world's livestock provides a range of options that are likely to be valuable in climate change adaptation, including resistance and tolerance to specific diseases, adaptation to poor-quality diets or to feeding in harsh conditions, and tolerance of climatic extremes. Breeding strategies to improve animals' abilities to cope with several climate-change related problems are possible and are likely to become increasingly important in the future.

The utilization of AnGR in climate change adaptation requires good knowledge of their characteristics and those of their current and potential future production environments. It is also important to ensure that potentially valuable genetic resources are not lost before they can be deployed. Improvements to characterization and conservation programmes are thus essential.

By the time the *Global Plan of Action for Animal Genetic Resources* was adopted in 2007, climate change had been widely recognized as a major challenge for agriculture, food security and for humanity as a whole. Both the Interlaken Declaration on Animal Genetic Resources and the preamble to the *Global Plan of Action* emphasize the links between AnGR management and climate change. Some four years later, the case for implementing the *Global Plan of Action*, and for its relevance to climate change adaptation and mitigation, remains strong. Effective implementation of the *Global Plan of Action* would be an important step towards improving the capacity of the AnGR sector, and the livestock sector more broadly, to respond to climate change – knowledge, availability (sustainable use, conservation and exchange) and strategies for use and development of AnGR would all be strengthened. While few aspects of improved AnGR management are relevant only in the context of climate change, certain policy and management measures stand out as being particularly significant. These include the following (grouped according to their relevance to the four strategic priority areas of the *Global Plan of Action*):

Strategic priority area 1. Characterization, inventory and monitoring of trends and associated risks

- developing methods for characterizing adaptive traits relevant to climate-change adaptation (heat tolerance, disease resistance, adaptation to poor diet, etc.) and for comprehensive evaluation of performance and use of animals in specific production environments and describing these production environments in a standard way;
- incorporating the above techniques into phenotypic characterization studies and AnGR surveys;
- improving knowledge and awareness of, and respect for, local and indigenous knowledge relevant to climate-change adaptation and mitigation;
- identifying potential climate change-related threats to specific AnGR, ensuring that long-term threats (e.g. gradual environmental changes) are monitored and that urgent action is taken to address immediate threats (e.g. small populations at severe risk from climatic disasters);
- exploring the possibility of modelling the future distribution and characteristics of production environments, to support the assessment of threats and the identification of areas that may be suitable for particular breeds in the future;
- improving knowledge of breeds' current geographical distributions to support the above

actions and to facilitate planning of climate-change adaptation measures and AnGR conservation strategies;

- improving the availability of the above-described knowledge, including via DAD-IS and other AnGR information systems;

Strategic priority area 2. Sustainable use and development

- ensuring that monitoring strategies and early-warning systems for AnGR are sensitive to climate-change-related trends and risks;
- ensuring that AnGR management planning is integrated into the planning of climate-change adaptation and mitigation measures at the level of the production system and nationally;
- exploring options for increasing carbon sequestration in pastureland through better grazing management, the role of AnGR in such measures, and the potential that they may offer for integrated approaches to climate-change mitigation, livelihood objectives, conservation of wild biodiversity and sustainable use of AnGR;
- strengthening cooperation among the international forums and organizations involved in AnGR management, other aspects of biodiversity, climate change adaptation and mitigation, and other environmental issues;
- ensuring that livestock keepers and other relevant stakeholders are involved in planning climate-change adaptation and mitigation measures within livestock production systems and the role of AnGR within these measures;
- building on, or integrating, local knowledge of how to cope with harsh and fluctuating production environments within climate-change adaptation strategies (as relevant and appropriate to future conditions and objectives);
- ensuring that plans to introduce breeds to new geographical areas take account of climatic and other agro-ecological conditions and their predicted future trends;
- reviewing and, if necessary, adapting breeding goals to account for the effects of climate change;
- improving access to inputs and livestock services relevant to climate-change adaptation;
- exploring the potential for the introduction of payments for environmental services as a means of promoting ecological and socio-economic sustainability in grazing systems and hence the maintenance of the associated AnGR;

Strategic Priority Area 3. Conservation

- ensuring that conservation strategies account for the observed and projected effects of climate change, including agro-ecological changes and disaster risk, and if relevant the effects of climate change mitigation policies;
- reviewing *in situ* conservation schemes to account for climate change-driven changes in the home production systems of the respective breeds;
- ensuring that *ex situ* collections are sufficiently comprehensive, well managed and well located to provide insurance against climatic and other disasters;

Strategic Priority Area 4. Policies, institutions and capacity-building

- promoting awareness among policy-makers of the potential roles of AnGR in climate change adaptation and mitigation;
- ensuring that national strategies and action plans for AnGR account for the effects of climate change and can be reviewed and amended as necessary to account for future climate-related

developments;

- promoting exchange of information on climate-change adaptation strategies for livestock systems and AnGR management, relevant breed adaptations and breed performance in specified production environments; and
- facilitating transparent, fair and equitable access to AnGR needed for climate change adaptation along with relevant associated knowledge and technologies.

I. INTRODUCTION

Animal genetic resources and their management

The objective of this background study paper is to describe the implications of climate change for the management of AnGR for food and agriculture (AnGR). Specifically, the focus is on the genetic resources of domesticated avian and mammalian species that contribute to food production and agriculture.

AnGR are used by humans to provide a wide range of products and services. Over time, a variety of breeds and types have been developed to provide these outputs in a wide range of production environments. Benefits accrue at various levels including the household, the national economy and the agro-ecosystem. AnGR management encompasses not only their current use, but also the activities needed to ensure their availability for the future; i.e. that their reproduction is managed appropriately; that their use is economically, socially and environmentally sustainable; and that if necessary conservation measures are implemented to reduce the risk of genetic erosion and extinction. It also involves development – both of the AnGR themselves through selective breeding and of production and marketing systems.

Much of the challenge in managing AnGR involves ensuring that animals are genetically well-matched to the production environments in which they are kept and to the demands placed upon them for products and services. Over time, this may require adjusting breeding objectives, bringing in AnGR from elsewhere or adapting husbandry practices (feeding, health care, housing, etc.). Another fundamental challenge is maintaining the genetic diversity that is a prerequisite for adapting livestock production systems to future changes.

Effective and sustainable use, development and conservation of AnGR require knowledge both of the resources themselves and of the production systems in which they are, or potentially could be, kept. Thus, management of AnGR also involves the characterization of livestock breeds, populations and production environments, and the retention and diffusion of AnGR-related knowledge. More broadly, the management of AnGR involves establishing policy and institutional frameworks that allow the various other aspects of management to be implemented effectively.

Throughout the paper, the main focus is on AnGR management as described above, rather than on broader livestock-sector policy in the face of climate change, although the latter forms an important part of the context and is discussed in the relevant sections and subsections below.

The significance of climate change for the management of animal genetic resources

Climate change comes as an additional factor influencing a livestock sector that is already highly dynamic. Change in livestock production systems is nothing new, but recent decades have seen rapid changes on an unprecedented scale – the so-called livestock revolution – driven mostly by rising demand for animal products, and facilitated by humans' increasing ability to control production environments and to move genetic material around the world. While these developments have enabled large increases in the output of animal products, they also pose challenges for AnGR management. On the one hand, greater capacity to move genetic resources has created new potential for mismatching animals and production environments. On the other, the spread of homogenized, highly controlled, production environments has led to the increasing worldwide dominance of the small number of breeds that produce well in these conditions, with a concomitant decline in overall breed and genetic diversity. At the same time, livestock-keeping has continued to play an important role in the livelihoods of large numbers of small-scale farmers and pastoralists, many of them among the world's poor. The livelihoods and livestock-keeping practices of these smaller-scale producers have, to varying degrees and *inter alia*, been affected by rising and changing market demand, increased competition, changing livelihoods and lifestyles, new employment opportunities and increasing pressure on natural resources. AnGR diversity has generally not fared well as a result of these changes and because of a widespread lack of adequate policies supporting sustainable use, development and conservation (FAO, 2007a).

The effects of climate change on AnGR and their management are likely to be felt in a number of ways and involve a range of mechanisms. Direct climatic impacts on livestock will interact with changes induced in other aspects of the agro-ecosystem (e.g. feed production and the epidemiology of diseases and parasites) as well as with policy and management interventions introduced to combat climate change and adapt to its effects.

The existence of diverse climate-related drivers of change – affecting a dynamic and differentiated livestock sector – mean that analysing the potential consequences of climate change for AnGR management is challenging both on a local scale and globally. When agro-ecological changes are observed, it is often difficult to distinguish the effects of climate against the background of ongoing change, much of which is induced by human activities both within and beyond the livestock sector. Policy adds another layer of complexity and uncertainty. Particularly in the wake of the livestock revolution, the need for more effective policy measures to address the various challenges affecting the livestock sector has become increasingly apparent (FAO, 2010a). Meeting surging demand for livestock products, supporting livestock-based livelihoods, reducing the effects of animal diseases (including zoonoses), and minimizing the negative environmental impacts of livestock production (including the emission of greenhouse gases) are among the most prominent requirements. The direct or indirect effects of climate change are likely to be felt in all these fields of action. In turn, the choice of approaches and tools used to tackle these broad livestock-sector issues has significant implications for AnGR and their management, both in terms of the potential contributions of AnGR diversity to meeting policy goals and the potential for policy measures to threaten diversity. AnGR do not, however, normally have a very high profile at policy level, although the adoption of the *Global Plan of Action for Animal Genetic Resources* (FAO, 2007b) is slowly changing this. Hence, from the perspective of AnGR management, policy measures are often additional external drivers of change that have to be reacted to.

While the various forms of climate change-exacerbated uncertainty pose a challenge for AnGR management, they also highlight the importance of retaining the capacity to adapt livestock production systems in response to future changes. The potential contribution of AnGR diversity to such adaptation is one of the most widely accepted justifications for pursuing policies and management strategies aimed at reducing genetic erosion in livestock species (FAO, 2007a). Realizing this potential requires not only ensuring that diversity is maintained, but also ensuring that the capacity to implement future adaptive management strategies is put in place. Thus, it requires giving attention to all the above-described aspects of AnGR management.

The world's AnGR are currently maintained largely within livestock production systems rather than in gene banks or other *ex situ* collections. Challenges to the sustainable functioning of these production systems are challenges both to the utilization and to the survival of the associated AnGR. As well as driving relatively gradual production-system changes that may adversely affect AnGR diversity, climate change also increases the risk that livestock populations will be affected by acute events, such as climatic disasters, that wipe out large numbers of animals and threaten specific breeds with extinction. In turn, both disruptions at the level of the production system and acute losses of AnGR diversity, threaten current and future food security, livestock-keeping livelihoods, and the various other agro-ecosystem services that livestock provide (nutrient cycling, seed dispersal, creation of microhabitats for wildlife, etc. – FAO, 2009a).

Structure of the paper

Section B of this paper discusses the challenges posed by climate change: the first three subsections deal with challenges associated with specific aspects of animal husbandry; the next subsection discusses, in more general terms, the challenges that may arise if climate-related changes mean that particular breeds are no longer well suited to the prevailing production conditions in the areas where they have traditionally been kept; the final subsection discusses potential implications for AnGR of climate-change mitigation policies and programmes within the livestock sector.

As well as being threatened by the effects of climate change, AnGR diversity provides opportunities for adapting production systems and ensuring that livestock products and services continue to be provided sustainably. Section C discusses this role of AnGR diversity as a potential resource in responding to climate change. Subsections are devoted to relocating AnGR, selective breeding, conservation and characterization. Section D presents some conclusions regarding the implications of climate change for AnGR management and highlights areas of AnGR management that require particular attention in the context of climate change.

II. CHALLENGES POSED BY CLIMATE CHANGE TO THE USE OF ANIMAL GENETIC RESOURCES

Challenges associated with the direct effects of a changing climate

Heat stress is known to alter the physiology of livestock, reducing production and male and female fertility, and increasing mortality rates. Animals' water requirements increase with temperature. Heat stress suppresses appetite and feed intake. Body temperatures beyond 45–47 °C are lethal in most species. In general, the high-output breeds from temperate regions, which provide the bulk of market production today, are not well adapted to heat stress. For example, milk production, fertility and longevity in Holstein-Friesian cattle decline as temperature increases (St-Pierre *et al*. 2003; West 2003). Such breeds are often less well adapted to high temperatures than the lower-output breeds that they have been displacing in recent years. For example, it has been shown that Large White sows are less heat tolerant than Creole sows (Gourdine *et al*. 2006; Renaudeau *et al*. 2007).

Temperature is predicted to increase globally, with reduced precipitation in many regions, particularly in already arid regions (IPCC, 2007). In general, livestock can adapt to small increases in temperature without great problems. Nonetheless, it can be expected that in parts of the world, temperature increases associated with climate change will have a significant negative impact on levels of animal production unless management is adapted. For example, a modelling exercise undertaken by Mader *et al.* (2009) for the Great Plains region of the United States of America indicated substantial declines in beef, dairy and pig productivity in parts of the study area (with improvements in some other areas in beef and pigs). Severe heat waves have caused substantial numbers of deaths in feedlot animals in the United States of America in recent years (Nienbar and Hahn, 2007; Hatfield *et al*., 2008) and the frequency, duration and intensity of such events is predicted to rise (IPCC, 2007; Diffenbaugh and Ashfaq, 2010). Many local breeds in the tropics and subtropics are comparatively well adapted to high temperatures. For them, the main climate change-relate problems are likely to be associated with feed availability (see below) rather than with high temperatures *per se*. Nonetheless, climatic conditions that induce heat stress are expected to become more frequent in Africa in the coming decades (Jones and Thornton, 2008). Non-adapted animals introduced to the tropics are already often affected by heat stress, particularly where high temperatures are combined with high relative humidity and diets based on poor-quality forage (King *et al*., 2006).

Options for alleviating heat stress include adjusting animals' diets to minimize diet-induced thermogenesis (low fibre and low protein) or by increasing nutrient concentration in the feed to compensate for lower intake; taking measures to protect the animals from excessive heat load or enhance heat loss from their bodies; or genetic selection for heat tolerance or bringing in types of animals that already have good heat tolerance (see Section C) (West 2003; Gwatibay *et al*., 2007; Renaudeau *et al*., 2010).

A variety of techniques can be used to keep animals cool. Options include simple shading, natural ventilation of buildings, mechanical ventilation using fans to increase air flow, use of water sprinklers to wet animals and enhance evaporative cooling, or the use of misters to increase evaporative cooling of the air (West 2003; Nienaber and Hahn, 2007). All these options require some degree of initial investment, some require access to relatively advanced technologies, and all except simple shading require ongoing input of water and/or power. The practicality of implementing cooling measures depends on the type of production system. They can most easily be applied in systems where the animals are confined and where the necessary inputs can be afforded and easily accessed. In extensive grazing systems, it is difficult to do more than provide some shade for the animals and possibly places for them to wallow. It is also difficult to implement cooling measures for animals that have to move about a lot, such as those used for transport. Livestock producers in areas where relative humidity is high face additional problems as there is less potential for the use of methods based on evaporative cooling.

Introducing technological adaptations to rising temperatures (cooling systems or adjusting animals' diets) is relatively easy in "industrial" production systems where animals are confined and heavy use of external inputs is the norm. This may make such systems relatively insensitive to the local-scale effects of climate change and allow them to continue to raise high-output non-locally adapted breeds, provided rising input prices do not undermine the economic sustainability of the high external input strategies. Small-scale producers who have adopted high-output breeds, but struggle to obtain the inputs needed to prevent the animals from becoming overheated, may find that their problems are exacerbated by climate change.

In addition to the physiological effects of higher temperatures on individual animals, the consequences of climate change are likely to include greater risk that geographically restricted breed populations will be devastated by the direct impact of extreme climatic events such as floods and hurricanes.[1] The risks associated with such disasters, and the potential for climate change to exacerbate them, have been recognized in the literature on threats to AnGR (Gibson *et al*., 2006; FAO, 2006a; FAO, 2007a; FAO, 2009b). However, the magnitude of these risks has not been assessed in depth (FAO, 2006a; FAO, 2007a). The impact of past climatic disasters on AnGR diversity is also unclear. It is possible to find numerous reports of floods and hurricanes that have caused the deaths of tens or even hundreds of thousands of animals: for example, by searching the DesInventar online inventory system of the effects of disasters.[2] Identifying whether such events have caused significant losses of AnGR diversity is more difficult. The DesInventar figures are not broken down by species, let alone by breed. Case studies of the impacts of climatic disasters on AnGR are also difficult to locate. There is some circumstantial evidence. For example, FAO (2006b) notes that the State of Yucatan in Mexico, where many backyard pigs were lost as a result of Hurricane Isodora in 2001, is home to the endangered Box Keken pig. As breed distributions become better mapped it may be possible to overlay them with maps of the location of past disasters (for historical analysis) and of disaster-prone areas (for risk assessment). To date, there seem to have been few, if any, systematic attempts to link breed distribution to climatic risks. A study of the distribution of British sheep breeds (Carson *et al*., 2009) indicated that many breeds are concentrated in a limited geographical area and are hence vulnerable to disasters and other localized threats. However, in the British context the main concerns were about disease epidemics and socio-economic threats rather than the direct impacts of climatic disasters (ibid.).

Challenges associated with the effects of diseases and parasites

The geographical and seasonal distributions of many infectious diseases, particularly those that are vector borne, as well as those of many macroparasites and pests of various kinds are affected by climate. Pathogens, vectors, and intermediate and final hosts can all be affected both directly by the climate (e.g. temperature and humidity) and by the effects of climate on other aspects of their habitats (e.g. vegetation). If the climate changes, hosts and pathogens may be brought together in new

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[1] The effect of extreme climatic events on the supply of feed and on disease epidemiology is discussed in the relevant subsections below.

[2] http://online.desinventar.org/

locations and contexts, bringing new threats to animal (and in some cases human) health and new challenges for livestock management and policy.

During recent decades, there have been significant changes in the incidence rates and/or distribution of several vector-borne diseases, including dengue, trypanosomiasis, leishmaniasis, Lyme disease, tick-borne encephalitis and bluetongue (De la Roque *et al*., 2008). However, it is difficult to single-out epidemiological changes that can be attributed unambiguously to climate change (ibid.). Interpretation of observed changes and prediction of future trends in disease distribution and impact is complicated by numerous factors that act simultaneously, and interact, with climate change. Prominent among these interacting factors are changes to landscape and land cover, changes in the abundance of disease hosts (including wildlife hosts), public health measures, trade, movements of human and animal populations, and a range of management, sociocultural, economic and political factors (De la Roque *et al*., 2008; Reiter, 2008; Epstein, 2001). For example, increased trade and population movement has enabled diseases to circumvent barriers such as oceans and deserts that once prevented their spread. Such effects have probably contributed more to the recent expansion of disease ranges than has climate change (De la Roque *et al*., 2008; Randolph, 2008).

The effects of climate change on the components of agro-ecosystems, including pathogens, have received increasing attention in the scientific literature in recent years. The mechanisms involved are complex and not fully understood. Overviews are provided by Hoberg *et al*. (2008) and De la Roque *et al*. (2008). A detailed discussion of this work is beyond the scope of this background study paper. Nonetheless, it is important to recognize that the available evidence suggests that risks associated with climate change are not simply a matter of gradual expansion of disease ranges into higher latitudes and higher elevations as average temperatures increase. Climate is characterized not merely by averages, but also by short-term fluctuations, seasonal oscillations, sudden discontinuities and long-term variations, all of which can influence disease distribution and impacts (ibid.). Further information on the effects of climate change on pathogens, particularly plant pathogens, can be found in the accompanying background study paper on micro-organism genetic resources (FAO, 2011a)

Changes to seasonal climates can have a significant influence on disease distribution. In the case of many tropical diseases, it is the cold of winter that prevents them from becoming problems in temperate zones. Shorter or warmer winters may enable pathogens to become established in new areas. Seasonal changes can also affect disease epidemiology in more complex ways as the lifecycles of the various organisms that play, or potentially play, a role in disease transmission are affected. For example, there may be an increase in the temporal overlap of the active phases in the lifecycles of such organisms, providing new opportunities for disease transmission. Moreover, the various factors that affect the rate of transmission of vector-borne diseases may be simultaneously affected by changes to temperature, potentially leading to large increases in the impact of the disease. Beyond certain thresholds of temperature, faster rates of development may mean that pathogens are able to utilize additional species as vectors.

Specific short-term weather events and/or seasonal rainfall patterns are known to be triggers for outbreaks of many diseases, including Rift Valley fever, African horse sickness, peste des petits ruminants, bluetongue and anthrax (Martin *et al*., 2008; Van den Bossch and Coetzer, 2008; FAO, 1999). It is predicted that climate change will lead to increases in the frequency of extreme weather events such as floods and droughts (IPCC, 2007). Flooding can contribute to the spread of water-borne diseases (Hoberg *et al*., 2008) and diseases that are spread by vectors that have aquatic phases in their life cycles. Restrictions to water availability can also contribute to the spread of disease: for example, when large numbers of animals congregate at a limited number of watering places. Another concern is that climate change will increase the risk that volatile weather may disrupt long-term ecological relationships that keep the spread of pathogens in check (De la Roque *et al*., 2008).

Rapid spread of pathogens, or even small spatial or seasonal changes in disease distribution, whether driven by climate change or not, may expose livestock populations to new disease challenges. The significance of this is not only that a larger number of animals may be exposed, but also that they are likely to lack the genetic resistance or acquired immunity that might have emerged had the animals or their ancestors previously been exposed to the diseases. The newly exposed populations may therefore experience more serious clinical disease. The problem may be confounded by a lack of experience on the part of the local livestock keepers in preventing and treating the unfamiliar diseases.

AnGR diversity potentially plays an important role in adapting production systems to the disease-related effects climate change (see Section C), but this diversity may be in turn be threatened by these effects. There are several ways in which such threats may operate: large numbers of animals may die as a result of disease epidemics; large numbers of animals may be culled in disease-control programmes; disease pressure may be one among several factors that contribute to making livestock-keeping livelihoods unsustainable; and regulations brought in to combat disease may restrict the type of livestock keeping practised and thereby threaten the associated AnGR (FAO, 2007a). In other words, disease-related threats can be both acute or chronic and can be caused by the direct effects of disease or indirectly by the measures used to control disease. Acute events (epidemics and culling campaigns) are particularly threatening to the survival breeds or populations that are found only within a limited geographical area (see also subsection above). The extent to which disease-related threats to AnGR will be exacerbated by climate change is not yet clear. However, if it results in diseases becoming more prevalent or shifting into previously unaffected areas, the threat will probably increase.

The most severe recent epidemics in terms of the numbers of livestock lost – those in which millions or hundreds of thousands of animals have been culled or died from disease – have involved quite a narrow range of diseases: most notably foot-and-mouth disease, avian influenza, African swine fever, classical swine fever and contagious bovine pleuropneumonia (ibid.). The extent to which these epidemics have affected AnGR diversity is not well understood. For example, losses are generally not distinguished by breed. However, evidence from the foot-and-mouth disease epidemic that struck parts of Europe in 2001 indicates that a number of rare breeds suffered substantial losses (Bowles *et al.*, 2003; FAO, 2007a; Roper, 2005; Country Report of the Netherlands, 2004). With the exception of African swine fever, the majority of deaths caused by the major recent epidemics of the above-mentioned diseases have resulted from culling rather than from "natural" causes.

The diseases that have led to large-scale culling are generally not among those whose distribution and impact is considered most likely to be affected directly by climate change (although, as discussed above, the influence of climate change on disease epidemiology is in general not well understood, particularly given the concurrent effects of other drivers of change). Stamping out a disease outbreak through mass culling is most feasible in situations where there are no vectors, intermediate hosts or wildlife reservoirs from which livestock can be re-infected. As described above, it is often such vectors and reservoirs that are considered to be the elements of disease ecology most likely to be affected by climate change. Thus, for example, the risk of an outbreak of foot-and-mouth disease (not vector borne) in Europe (currently no wildlife reservoirs in this region) is not thought likely to be affected by climate change (Dufour *et al.*, 2008) and thus climate change does not appear to directly increase the risk to AnGR from foot-and-mouth disease-related culling. In the case of avian influenza, climate change is likely to have some influence on the migration patterns of wild birds and hence on the distribution of the disease, but the significance of such changes for the impact of the disease on domestic poultry populations remains unclear (Gilbert *et al.*, 2008). The direct impact of climate change on the highly pathogenic type may be limited as the disease circulates mostly among domestic birds; indirect effects are possible due to the influence of climate change on poultry management systems (ibid.).

While it is culling that has usually posed the greatest threat to AnGR diversity, the direct impact of livestock mortality brought about by disease epidemics should not be overlooked. In recent years, the most devastating disease in terms of killing a large proportion of the animals in affected areas has probably been African swine fever (FAO, 2007a). The role of ticks and wild relatives of domestic pigs in the transmission of this disease means that climate change may have some effect on its distribution and impact. However, the potential impact of such changes on AnGR diversity remains a matter of speculation. Because figures are not broken down by breed, little can be concluded about the overall impact of past disease-induced mortality on AnGR diversity. However, some relevant examples have been reported. The Country Report of Japan (2003) submitted during the preparation of *The State of the World's Animal Genetic Resources for Food and Agriculture* (FAO, 2007a) reports that in 2000, approximately one-third of the population of the rare Kuchinoshima cattle breed on the country's Kuchinoshima Island died from a disease "transmitted by mites". Lungu (2003, cited in FAO, 2007a) reports that the indigenous Tonga breed was particularly affected by outbreaks of corridor disease that led to a decline of 30 percent in the cattle population in Zambia's Southern Province. There is no indication that climate change played a role in these cases.[3] However, such losses to localized, sometimes rare, livestock populations caused by shifts of vector-borne diseases into new areas, are examples of the type of impact that climate-related epidemiological changes might have on AnGR.

One development, possibly related to climate change, that is causing concern from the AnGR perspective is the spread of bluetongue virus in Europe (University of York, 2009). Again, the main concern is about breed populations concentrated in limited geographical areas (Carson *et al*., 2009). African horse sickness is, in some respects, a similar case. This disease – which is spread by the same type of midge as bluetongue – is considered a candidate for climate-change induced spread (Dufour *et al*., 2008). The rate of mortality in infected animals is very high and legal requirements for the slaughter of infected animals or those showing clinical symptoms (EU, 1992) could pose an additional threat to rare breeds.[4]

Challenges associated with livestock feeding and nutrition

All livestock production depends on access to the feed and water that animals need to survive, produce and reproduce. Vast areas of the world are used for producing livestock feed. Pasture accounts for about 26 percent of the world's ice-free terrestrial area (FAO, 2010a). About one-third of cropland is used for producing animal feed. Combined, these areas represents almost 80 percent of all agricultural land (ibid). Yet more arable land provides crop residues used for feeding livestock, and the seas provide fishmeal. The future of livestock production systems, and of the associated AnGR, depends on the continued productivity of these various feed-producing areas – all of which are potentially affected by climate change.

The influence of the climate on the distribution of plant communities is complex. The effects of climate interact with those of other physical aspects of the environment (e.g. soil characteristics). As well as its direct effect on plants, climate influences the distribution of the various other biological components of the agro-ecosystem – pests, diseases, herbivorous animals, pollinators, soil micro-organisms, etc. – all of which in turn influence plant communities. Detailed discussion of the potential effects of climate change on the distribution and activity of pathogens, soil micro-organisms, pollinators and biological control agents can be found in the accompanying background study papers on micro-organism and invertebrate genetic resources (FAO, 2011a,b). Different species have different capacities to migrate in response to climate change. Species that flourish only in very specific environments are more likely to be disadvantaged by climate-related agro-ecosystem changes than are generalist species that can survive in a variety of different environments (Foden *et al*., 2008). Generalist or colonizing species may take advantage of climate change to expand their ranges, potentially leading to new areas being invaded by weeds, pests, pathogens or disease vectors. When usually interacting species have different phenological and evolutionary responses to climate change, differential range expansions may lead to new species relationships and trophic encounters (plant/herbivore, pathogen/host, predator/prey, etc). All these processes have the potential to influence directly or indirectly the growth of the plants on which livestock feed.

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[3] There have been suggestions that the distribution of corridor disease – a tick-borne disease – might be affected by climate change (IPCC, 2001).

[4] The effect compulsory movement controls, which could cause severe disruptions and economic losses in the equine sector (Allison *et al*., 2009), could also be a threat to the ongoing use of particular breeds.

Climate directly affects the quality and quantity of the forage[5] that can be produced in a given area. In general, increases in temperature, carbon dioxide levels, precipitation and nitrogen deposition increase primary production in pastures (Tubiello *et al*., 2007). As long as water requirements can be met, the increases in temperature that are predicted to occur in temperate regions may benefit early season plant growth and enable more productive forage species to be grown. In this respect, conditions in the affected areas may become more suitable for keeping higher-output livestock breeds that require good diets.

Conversely, many already semi-arid areas are predicted to experience lower rainfall as a consequence of climate change. The length of the growing period is expected to decrease in many parts of the tropics, and this may be accompanied by greater variability in rainfall patterns – with more frequent droughts (IPCC, 2007; Thornton *et al*., 2006, 2008). This is likely to increase the risk that animals will suffer lengthy periods of nutritional stress. In addition, animals may be required to walk longer distances in search of feed and have to cope with less frequent watering. The movement of animal populations out of drought-affected areas can lead to problems of overgrazing in neighbouring areas and to problems with diseases and parasites as animals crowd together or move into areas where unfamiliar diseases are endemic. Conflict over access to grazing land and water is another potential hazard.

High temperatures tend to increase lignification of plant tissues and hence decrease the digestibility of forage. It is also predicted that climate change will induce a shift from C3 to C4 grasses (Christensen *et al*., 2004; Morgan *et al*., 2007). C4 plants are more efficient in terms of photosynthesis and water use than C3 plants. Both types coexist in the tropics, but react differently to increases in temperature and carbon dioxide levels. In addition to various changes in ecosystem function (Easterling and Apps, 2005; Easterling *et al*., 2007; Tubiello *et al*., 2007), a shift from C3 to C4 grasses has direct implications for forage supply. C3 forage plants generally have higher nutritive value, but yield less, while C4 plants contain large amounts of low-quality dry matter and have a higher carbon–nitrogen ratio.

Climate change may increase shrub cover in some grasslands (Christensen *et al*., 2004; Morgan *et al*., 2007). Shrub encroachment tends to reduce the quantity of forage available for livestock. In terms of forage quality, browse (i.e. the edible parts of shrubby vegetation) often has a higher protein content than grasses, but the digestibility of natural browse can be lower than that of grasses because of the presence of secondary metabolites (Illius, 1997).

Few ecosystem models have attempted to predict the overall effects of climate change on rangeland systems. Tietjen and Jeltsch (2007) conclude that current models insufficiently reflect the impact of increased carbon dioxide levels and changes in intra-annual precipitation patterns on plant productivity, and provide little useful guidance for livestock keepers or land managers. Moreover, climate change-driven changes to vegetation are only one of the many drivers of change affecting grassland-based livestock production systems. Pressure on feed resources and other constraints to traditional mobile livestock-keeping livelihoods have promoted the spread of agropastoralism (i.e. livelihoods that involve some crop production in addition to livestock keeping) at the expense of pastoralism. Herrero *et al*. (2008) predict a further shift in livestock population from grassland to mixed production systems over the period to 2030.

While climate change may exacerbate the problems faced by pastoralists, it is also predicted that in some areas crop production will become increasingly marginal and risky (Jones and Thornton, 2008). This may increase reliance on livestock keeping in these areas (ibid.). In mixed-farming systems, climate change can be expected to influence the quantity and quality of feed available from various sources (forage crops, crop residues, weeds, uncultivated areas, etc.). However, the availability of these resources and the intensity with which they are used will be influenced by other factors, such as human population density, competing land uses, demand for crop and livestock products,

[5] The term "forage" refers to the edible parts of plants other than separated grain.

technological developments and their adoption, and the opportunity costs of labour (Baltenweck *et al.*, 2003; Herrero, *et al*., 2008).

High temperatures and lack of rain are not the only climatic threats to livestock's ability to survive on locally produced feed resources. A thick cover of snow or ice may mean that animals are unable to graze. If the problem lasts for an extended period and no alternative source of feed is available, the animals may starve to death. The most devastating events of this kind are the *dzud* disasters that occur from time to time in Mongolia. The term *dzud* is used to describe a number of winter climatic conditions or climate-related events that prevent animals from grazing or drinking: very thick snow cover; formation of an impenetrable layer of ice; absence of unfrozen water; extreme cold and strong wind; overgrazing problems as animals move into the limited areas where feed is available; and combinations of these various circumstances (Batima, 2006). Herders are used to dealing with such events on a local scale, but when wide areas are affected for long periods, very large numbers of animals die. The winter events are exacerbated if they are accompanied by summer droughts. The period from 1999 to 2003 saw a series of *dzuds* and droughts that killed more than 12 million head of livestock (ibid.). Another major *dzud* disaster occurred during the 2009/2010 winter. It is predicted that climate change will lead to milder, snowier, winters in Mongolia and hence to greater risk of *dzuds* (ibid.) (periods of mild winter weather melt snow which may then freeze into a hard layer of ice).

As with floods and hurricanes, the effects of droughts and *dzuds* on AnGR diversity have not been well documented. Coping mechanisms – often based on mobile grazing strategies – have enabled many livestock-keeping communities in dryland areas to survive the droughts of the past and to retain sufficient AnGR and associated knowledge to re-establish their herds and flocks. Nonetheless, if climate change brings more severe and frequent droughts – particularly in combination with other factors that disrupt drought-coping mechanisms – AnGR diversity may suffer, both because of the immediate impact of livestock deaths and more chronic effects on livestock-keeping livelihoods. As in the case of most climate change-related effects, exacerbated drought is only one among several pressures affecting the production systems concerned.

So-called landless production systems – at least those that are of the "industrial" rather than "backyard" type – are better able than land-based systems to isolate animals from local-scale changes in the availability of feed resources, including those that may arise because of climate change. Landless producers draw on feed supply chains that operate on a global scale and have access to a range ingredients that can be used to formulate diets that provide animals with the nutrients they require in the most cost-effective way (Rowlinson, 2008). Nonetheless, the economics of landless production may be affected by the impact of climate change on the price of feed. The latter may arise in several ways, including direct impacts of climate on feed-crop productivity, the influence of climate on alternative demands for feed inputs (e.g. biofuel) and climate-change mitigation measures introduced in the crop sector.

In production systems where animals are fed on concentrates, rising grain prices (whether or not driven by climate change) increase the pressure to use animals that efficiently convert grains into meat, eggs or milk. Thus, within such systems climate change may lead to greater use of poultry and pigs at the expense of ruminants, and greater focus on the breeds that are the best converters of concentrate feed under high external input conditions. Increases in the price of grain may also contribute to the further concentration of production in the hands of large-scale producers. For example, smaller-scale producers in the Russian Federation were more severely hit than their larger counterparts by the grain price rises that followed the heat wave and drought of 2010.[6] By promoting a more homogeneous livestock sector, such changes may have negative consequences for AnGR diversity. The other side of the equation is that the expansion of large-scale landless production in recent decades has been underpinned by the availability of cheap grain and fuel. Various pressures

[6] Financial Times, 22 November 2010 (http://blogs.ft.com/beyond-brics/2010/11/22/russia-rising-feed-costs-drive-farmers-to-cull-livestock/).

(e.g. increasing demand for human food and biofuel, rising oil prices, pressure on water resources) – potentially exacerbated by climate change – mean that this era of cheap external inputs may be coming to an end (Rowlinson, 2008). If this happens, producers may find it necessary to make more use of locally available feeds (Farrell, 2005; FAO, 2008a; Holechek, 2009). This would imply the use of breeds and species that can make good use of these resources. The potential vulnerability of large-scale landless production to increases in input costs was illustrated in Southeast Asian countries, such as Indonesia, during the economic crisis of the late 1990s (Sudaryanto, 2001). In the case of the dairy sector, Hayes (2009) referring to the Australian industry, predicts that rising price of grain will lead to a greater reliance on pasture as a source of feed and the need to breed for cows that are well adapted to this type of production.

In summary, climate change has the potential to affect the availability of livestock feed in a range of ways and may pose major problems both for the livestock sector as a whole and for specific production systems and their associated AnGR. In land-based systems, these effects come in addition to a range of ongoing problems – unsustainable grazing and cropping practices and water use, infrastructure development and fragmentation of rangeland ecosystems, etc. – affecting feed availability. In the case of production systems that rely on purchased feed, climate change can, similarly, be regarded as one among several factors that may undermine the sustainability of feed supplies and current feeding practices.

Challenges associated with shifting breed and species distributions

Although locally adapted breeds can be expected to cope with the effects of climate change more easily than their exotic counterparts, rapid and substantial changes to local climate may outstrip the capacity of local animal populations to adapt through natural or human selection or of livestock keepers to adapt their husbandry methods. This may give rise to the need for breed or species substitution. Species substitution (e.g. increased use of dromedaries) because of climatic and vegetation changes has already occurred in parts of Africa (Gouro *et al.*, 2008; MacOpiyo *et al.*, 2008). Changes have also occurred at breed level. Blench (1999) describes an expansion in the distribution of the drought-tolerant Azawak cattle breed in West Africa, and Blench and Marriage (1999) describe how Fulbe herders in Nigeria, faced with a shortage of grass in the semi-arid zone, switched to keeping the Sokoto Gudali cattle breed, which copes well with a diet of browse, instead of the Bunaji breed.

The emergence of mismatches between AnGR and their production environments because of climate change, and the potential for moving species and breeds into new geographical areas, represent both challenges and opportunities for AnGR management. If it becomes difficult (in physiological or socio-economic terms) to maintain a breed in its home area, it may be faced with the risk of extinction. Conversely, introducing a breed to a new area may provide both new opportunities for keeping it in use and new opportunities for local livestock producers to adapt to climate change. Such challenges and opportunities are intertwined elements within the process of change and should be addressed in a joined-up way when taking decisions regarding the introduction of breeds or species to new areas. However, in keeping with the overall structure of the paper, this subsection focuses on the threats to AnGR diversity posed by changes to the geographical distributions of breeds, species and production environments. Discussion of livestock diversity as a resource in meeting the challenges posed by climate change can be found in Section C.

In the case of wildlife, attempts have been made to forecast extinctions by identifying “climatic envelopes” for species based on their current distributions and then identifying the size and location of the equivalent envelopes under future climate-change scenarios, with extinction probabilities calculated based on the size of the species’ predicted future areas of distribution (Thomas, 2004). While such approaches may provide indications of the likely consequences of climate change for species diversity, results should be interpreted with caution because many factors other than climate – soil and land-cover characteristics in the target area, competition for resources, evolutionary responses, migratory capacity, etc. – affect species distribution (Pearson and Dawson, 2003).

Among domesticated animals, the distribution of species and breeds is heavily influenced by direct human interventions. Animal husbandry (provision of housing, supplementary feed, veterinary care, etc.) can greatly extend the areas in which particular types of animal can be kept. Conversely, distribution, both currently and in the future, may be restricted not only by climatic factors but also by socio-economic and cultural factors. Thus, for many breeds, straightforward climatic models, or even those that account for changes to the distribution of interacting species such as feed plants and pathogens, are unlikely to be adequate for predicting future distribution and extinction probabilities.

An alternative approach to identifying climate change-related extinction risk in wild species focuses on identifying characteristics that make species vulnerable to climate change. Foden *et al.* (2008) identify the following factors: specialized habitat and/or microhabitat requirements; narrow environmental tolerances or thresholds; dependence on specific environmental triggers or cues that are likely to be disrupted by climate change; and poor ability to disperse or colonize new areas.

Identifying the factors that make livestock breeds vulnerable to the effects of climate change (or other threats) may be a valuable means of identifying preventive steps that can be taken to reduce the risk of extinction. However, the factors involved would probably differ considerably from those in wildlife and might be very location specific. As discussed above, breeds' capacity to survive the effects of climate change in their home zones is not simply a matter of their biological capacity to adapt, but also of how their management can be adapted. Capacity to adapt livestock management practices in response to climate change is, in turn, influenced both by access to inputs (external inputs and local natural resources) and by knowledge (traditional or newly acquired) of the local production environment. Breeds' abilities to "disperse or colonize" new areas may be influenced by their physical capacities, but a major shift in a breed's distribution requires a human decision to start keeping it in a new area, as well as the wherewithal to move and establish it successfully. Motorized transport and reproductive technologies provide opportunities to move breeds further and more easily than could be done in the past, often with little or no reliance on the animals' ability to make the journey on foot. Moreover, although many individual breeds are associated with specialized production environments, their distributions tend to be restricted not so much by their inability to survive outside these production environments as by the economic advantages of keeping "mainstream" breeds in areas where the production environment is less challenging. Likewise, a breed may be threatened not because its home area becomes less hospitable, but because it becomes more hospitable – allowing the introduction of breeds that are more competitive economically. Thus, assessing the threat that climate change poses to particular breeds (or to the overall state of AnGR diversity) requires knowledge not only of the relationships between the breeds' adaptive traits and the changing state of their biophysical environments, but also of the breeds' management and how it can be adapted, the breeds' socio-economic and cultural strengths and weaknesses relative to other types of livestock in their home zones and in potential areas of introduction, and of the capacity of the relevant stakeholders to manage any shifts in distribution successfully.

While socio-economic, cultural and policy factors are likely to mediate the effects of climate on AnGR diversity and breed distribution, physical geography also needs to be considered. For example, an advancing frontier of unsuitable climate may push a breed's distribution up against a barrier to migration such as the sea or a large mountain range. In the case of breeds from low-lying islands, it is possible that the whole of their zones of origin may end up under water if sea levels rise because of climate change.[7] Conversely, physical aspects of the production environment that are not affected by climate change (e.g. elevation, slope, rockiness of terrain) may prevent the advance of mainstream breeds that would otherwise displace locally adapted breeds (e.g. in mountain areas) as the climate becomes milder. Reindeer provide an interesting example of a specially adapted animal whose distribution may be restricted directly (i.e. not because of competition) by an "improvement" in the climate. Warmer winters result in more frequent freezing and thawing of the snow, which can lead to

[7] http://www.spc.int/lrd/index.php?option=com_content&view=article&id=654:life-on-the-front-line-in-the-south-west-pacific&catid=2:animal-genetics&Itemid=65

the formation of a hard layer of ice that the reindeer cannot break through in order to feed (Reinert *et al.*, 2008) (see also discussion of *dzuds* in the subsection on feed above).

The most straightforward objective for modelling the relationships between climate change and the distribution of AnGR is probably that of identifying geographical areas where agro-ecological shifts driven by climate change are likely to be so substantial and rapid that the breeds currently present will no longer be suitable and will not adapt genetically with sufficient speed. In this way, vulnerable locations might be identified for more in-depth investigation and if necessary practical support in adapting livestock production to changed conditions. Breeds threatened by such changes might also be identified as targets for conservation programmes or measures to support sustainable use. Aside from the complexity of the mechanisms involved, the other big challenge with regard to modelling the effects of climate change on AnGR is that the data needed as inputs for such models are generally lacking. Detailed studies of breeds' physiological and behavioural adaptations to environmental stresses are rare. Data on breeds' distributions and production environments, which give an indication of their probable adaptive characteristics, are also generally inadequate and incomplete (see further discussion in the subsection on characterization in Section C).

Challenges associated with climate change mitigation measures

Livestock production is a major contributor to global emissions of greenhouse gases (FAO, 2006c). Greenhouse gas emissions occur throughout the livestock production cycle. Feed-crop production and management of pastures give rise to emissions associated with the production and application of chemical fertilizer and pesticides and with the loss of soil organic matter. Further emissions occur because of the use of fossil fuels in the transport of animal feed. Forest clearance to create pastureland, or cropland for growing animal feed, releases large amounts of carbon into the atmosphere. Further emissions occur directly from the animals as they grow and produce: most notably, ruminant animals emit methane as a by-product of the microbial fermentation through which they digest fibrous feeds. Emissions of methane and nitrous oxide occur during the storage and use of animal manure. Processing and transport of animal products give rise to further emissions, mostly related to use of fossil fuel and infrastructure development (ibid.). Various technical options are available for reducing emissions from the livestock sector and for enhancing the sequestration of carbon in land used for livestock production. These measures can be promoted in various ways as elements of climate-change mitigation policy.

Efforts to reduce emissions from the animals themselves focus on improving feed conversion efficiency (less emission per unit of meat, milk, etc. produced) and reducing the amount of methane produced during digestion (FAO, 2010a). Both are affected by the type of animal kept and the nature of the production system. Monogastric animals such as pigs and chickens have relatively good feed convertion ratios and their digestive processes produce less methane than those of ruminants. Within species, certain breeds and lines have been intensively bred for high output and good feed conversion ratios under high external input conditions. Such breeds increasingly dominate global livestock production. Other breeds have been subject to different selection pressures. For example, many locally adapted breeds are not, at least in a narrow sense, particularly efficient feed converters; rather they have been selected for their ability to survive in harsh production environments and, in many cases, to provide a range of products and services many of which are not accounted for in conventional assessments of livestock output and productivity.

The production systems in which locally adapted breeds are usually kept are also not the most well suited for achieving high feed conversion ratios and low methane emissions. Ruminants fed on poor quality (high fibre and low protein content) diets tend to produce more methane per unit of dry matter digested than animals fed on better quality forages or appropriately supplemented with concentrate feed. For example, Ulyatt *et al.* (2002) report higher methane emissions from animals fed on subtropical C4 grasses than from those fed on temperate C3 grasses. In contrast, high external input production systems provide the conditions that high-output breeds need to meet their genetic potential as efficient feed converters. These systems access global feed chains that enable them to formulate diets that allow good feed conversion ratios and low methane emissions.

Technical options for reducing greenhouse gas emissions per unit of output include adjusting animals' diets so that they better match nutritional requirements and/or can be digested with less production of methane. Improving animal health care can further improve feed conversion efficiency (FAO, 2010a). Better feeding, health care and general husbandry can be complemented by selective breeding for higher output or by bringing in higher-output AnGR for use either in cross-breeding or as pure-breeds. However, care is needed to ensure that production environments and animals remain well-matched to each other. The overall efficiency of the production process – output relative to greenhouse gas emissions – will suffer if the animals' fertility or survival rates decline because the animals are poorly adapted to their production environments. If improvements to the efficiency of livestock production are achieved through balanced development that takes account of the need for appropriate and sustainable use and development of AnGR and, if needed, for the implementation of conservation measures, there is no reason why they should be a particular threat to AnGR diversity. Unfortunately, however, this is far from being the case at present. Inadequate policies, both for the livestock sector as a whole and for AnGR management, are regarded by many stakeholders as among the most significant threats to diversity (FAO, 2009b). If regulatory or market-based policy measures are used simply to "punish" production systems that are deemed to be high emitters of greenhouse gases (particularly if the emphasis is on reducing methane emissions) the associated AnGR diversity may decline.

If emissions along the whole chain of production are taken into account, the carbon footprint of high external input systems tends to look less impressive because of their heavy use of fossil fuels (carbon dioxide emissions) and problems with the management of manure (methane and nitrous oxide emissions). Also significant is the fact that such systems usually produce only one type of output, while livestock in smallholder and pastoral systems frequently provide a range of products and services. Efforts to assess greenhouse gas emissions throughout the whole "lifecycle" of animal products have begun only quite recently, still involve a number of hypotheses and generalizations, and have not yet accounted for all types of benefit derived from livestock (e.g. savings and insurance functions) (FAO, 2010b). The first such study undertaken by FAO focused on the dairy sector. Results of a modelling exercise indicated that highest greenhouse gas emissions per unit of fat and protein corrected milk (FPCM) occurred in the developing regions of the world, while the lowest emissions per FPCM were in Europe and North America. Grazing systems were found to have higher emissions than mixed systems (ibid.). There is no straightforward means of translating this kind of preliminary analysis into practical climate-change mitigation policies. As the report of the study concludes "the real challenge lies in identifying approaches to reduce emissions" (ibid.). This will require not only fuller understanding of the technical issues involved, but also evaluation of the various trade-offs that may arise between climate change mitigation, livelihoods, food security, and other environmental concerns such as pollution of water, air and land, and loss of biodiversity.

Grazing systems present a particular biological and policy challenge. On the one hand, they rely mainly on ruminant animals, often feeding on low-quality forage, and therefore involve high levels of methane production. On the other, the grazing systems of the developing world provide livelihoods to large numbers of livestock keepers, many of whom are poor and have few alternatives available. Many grazing systems make use of land that is unsuitable for crop production and therefore provide animal products without competing with direct production of crops for human consumption. Grasslands have great potential for carbon sequestration in the soil, but if managed badly can release large amounts of carbon into the atmosphere. It is difficult to generalize about the influence of livestock grazing on carbon sequestration in grasslands. Overgrazing increases the loss of soil carbon, but well-managed grazing can increase carbon deposition. Carbon accrual under well-managed grazing can be greater than that in ungrazed land, although this depends on the types of grazing, plant communities, soils and climate involved (Smith *et al*., 2008). In some circumstances, the "negative" argument that livestock keeping provides an alternative to more damaging types of land use may also be relevant.

The 2007 report of the Intergovernmental Panel on Climate Change (IPCC, 2007) recognizes both the major potential significance of carbon sequestration in soil and the probability that there will be fewer barriers to the adoption of climate-change mitigation measures if they also contribute to improving livelihoods and to climate-change adaptation. Similar arguments about synergies between climate-change mitigation and improved food security and livelihoods through improvements to crop and livestock production among smallholders and pastoralists are put forward by FAO (2009c). Such opportunities have not dominated the debate over livestock and climate change, but some effort has been made to identify development measures for dryland grazing systems that address both the need to improve local livelihoods and the need to improve the rate of carbon sequestration vs. carbon loss from the soil (FAO, 2009d). Promising approaches have been identified, but several constraints need to be overcome if the desired outcomes are to be achieved. Key barriers include:

> *"land tenure, common property and privatization issues; competition from cropping including biofuels and other land uses which limit grazing patterns and areas; lack of education and health services for mobile pastoralists; and policies that focus on reducing livestock numbers rather than grazing management."* (ibid.).

If climate-change mitigation policies that focus on adapting and building upon existing livestock-keeping livelihoods prevail, and constraints to their implementation are overcome, locally adapted grazing animals will be essential to their success. The respective AnGR will, in turn, be kept in use within more sustainable production systems. The default option in such circumstances would probably be to use the breeds and species that are already available locally. AnGR stakeholders would need to ensure that AnGR management is well integrated within the overall planning of the mitigation and adaptation measures, and that any breed or species introductions or breeding programmes contemplated are appropriate to local conditions and trends. Conversely, as noted above, it is possible that climate change mitigation policy, by seeking to discourage "inefficient" extensive grazing, could create additional threats to AnGR diversity in drylands. This kind of scenario would require AnGR stakeholders to seek to promote sustainable use and conservation of the affected breeds in whatever ways are relevant, feasible and appropriate to the circumstances. More generally, the vast size of the world's dry rangelands and their potential role as sinks or emitters of carbon, coupled with the concentration of AnGR diversity in these zones (FAO, 2006d) and the importance of livestock in the livelihoods of local people, means that these zones are sites of major overlap between AnGR management and the management of other natural resources and between the work of various international bodies and forums, including the Commission on Genetic Resources for Food and Agriculture (CGRFA), Convention on Biological Diversity and the United Nations Convention to Combat Desertification. The potential for synergies and more joined-up approaches has scarcely been tapped at policy level (FAO, 2009d). Sustainable management of dryland production systems involves the provision of globally significant public goods including carbon sequestration and maintenance of AnGR diversity. This raises the question of how local livestock keepers can be rewarded for supplying these public goods, including the possibility of introducing schemes that provide payments for environmental services (FAO, 2007c).

Grazing systems in the temperate zones of developed countries are also potential targets for carbon sequestration measures. In some such areas, policy-makers' attention may already be shifting away from food production towards the management of carbon and other aspects of the agro-ecosystem such as water, wild biodiversity, landscapes and alternative rural livelihoods (Gibon, 2005; Ostle *et al*., 2009; Reed *et al*., 2009). Promoting carbon sequestration may entail lower stocking rates, but the popularity of livestock grazing as a tool in wildlife and landscape management has been growing in recent years. There is increasing awareness of the advantages of using locally adapted AnGR for such purposes and of the potential contribution of speciality products from local breeds to rural livelihoods. Payments for environmental services, whether carbon sequestration, landscape management or biodiversity conservation, could help promote both the economic and the ecological sustainability of grazing systems and hence contribute to the retention of the associated AnGR. Thus, there are likely to be opportunities for integrating sustainable management of AnGR within broader rural development polices that also include climate change mitigation measures. It is important to ensure that such opportunities are taken, for example, through the inclusion of relevant provisions in national strategies and action plans for AnGR.

III. THE POTENTIAL ROLE OF ANIMAL GENETIC RESOURCES IN ADAPTATION TO CLIMATE CHANGE

Many generations of natural selection and human-controlled selective breeding and husbandry, in a wide range of production environments, have given rise to great genetic diversity among the world's livestock. Breeds and populations that have been exposed to climatic extremes, heavy disease and parasite challenges, poor quality feed, high elevations or difficult terrain have often developed adaptations that enable them to thrive where other animals struggle to survive. Although advances in feeding, housing and veterinary care have increasingly enabled the establishment of production systems that isolate animals from such stresses, locally adapted animals remain essential to many livestock-keeping livelihoods especially in marginal areas.

The range of species, breeds and within-breed diversity maintained today in the world's livestock production systems constitute the main source of AnGR available to the livestock sector as it responds to the challenge of climate change. Much of this diversity remains in the hands of livestock keepers – many of them small-scale farmers or pastoralists – who both rely on their animals for their day-to-day livelihoods and act as custodians and developers AnGR (FAO, 2009a). *Ex situ* collections are far from complete in their breed coverage. The 169 country reports submitted during the preparation of *The State of the World's Animal Genetic Resources for Food and Agriculture* (FAO, 2007a) indicated that only 37 percent of countries had any *in vitro* conservation programmes.[8] A further survey conducted in 2010 produced responses from 90 countries, 20 percent of which reported that they had fully operational gene banks, with a further 50 percent reporting plans to establish a gene bank within five years (FAO, 2010c).

The first steps in adapting production systems to the effects of climate change are likely to involve attempts to alter husbandry practices rather than to make major changes in the utilization of AnGR, such as introducing new breeds or adjusting breeding strategies. For example, as described in Section B, various technologies can be used to protect animals from the direct effects of rising temperatures. Similarly, vaccinations and other preventive measures can be used against many of the diseases and parasites that may spread into new areas as a result of climate change.

A detailed review of potential livestock development interventions, and their relevance to climate change adaptation, is beyond the scope of this paper. However, the introduction of new technologies has often proved difficult in the low external input production systems of developing countries. In many pastoral, small-scale mixed farming and backyard production systems "high-tech" cooling systems are beyond the means of most livestock keepers. Their applicability is, anyway, limited in systems where animals are dispersed over wide areas. The delivery of veterinary services to poorer livestock keepers, particularly those who live in remote areas, is inadequate in many countries. Providing sufficient good-quality feed is already a big challenge for many livestock keepers, particularly if they are attempting to raise high-output breeds. On the positive side, many livestock-keeping communities in marginal production environments are highly experienced in managing livestock in the face of harsh and variable climatic conditions (Reinert *et al*., 2008; FAO, 2009a; SAVES, 2010). This experience is likely to be an asset in climate change adaptation whether or not AnGR management in the narrow sense (breeding objectives and breed/species choice) is adjusted. It is important that livestock development- and climate change-adaptation policies support rather than constrain the existing adaptive capacities of livestock-keeping communities, but also that relevant technical and financial support is provided where necessary (UNPFII, 2008).

[8] And only 52 percent reported any kind of organized *in vivo* conservation projects.

Industrial-type "landless" production systems have far greater capacity to access and utilize the technologies needed to protect their animals from the local-scale effects of climate change. Indeed, if sufficient resources are made available it is possible to create the conditions needed for raising high-output animals that lack local adaptations almost anywhere. For example, "desert dairies" housing Holstein-Friesian cows have been established in some Middle Eastern countries. However, as discussed above, the long-term sustainability of relying on such solutions in a world affected by rising feed and fuel prices is questionable. It should also be recalled that not all livestock production in developed countries occurs in industrial conditions. Production systems in these countries also include mixed farming and grazing systems of various types. While additional veterinary, feeding and cooling technologies can be introduced in such systems, animals cannot be fully isolated from the local environment.

The overall trend in recent decades has been towards the development of livestock production systems that meet the needs of high-output livestock rather than towards the greater deployment of genetic diversity to facilitate production in diverse conditions. Even in the face of climate change, this trend is likely to continue, in the short term at least. However, it is not universal and not entirely stable. The need for locally adapted animals is likely to remain strong in many production systems. In some circumstances there may be increasing need to utilize specific climate-related adaptations. The remainder of Section C is devoted to discussing the potential of the world's AnGR to meet such needs and some of the technical and policy challenges involved.

Adaptive characteristics currently available among the world's animal genetic resources

Tolerance of climatic extremes

There are substantial differences in thermal tolerance between livestock species and among breeds within species. Ruminants generally have a higher degree of thermal tolerance than monogastrics. The ability to thermoregulate depends on complex interactions among anatomical and physiological factors. Properties of the skin and hair, sweating and respiration capacity, tissue insulation, surface area relative to body weight or lung size, endocrinological profiles and metabolic heat production are among factors known to influence heat loads. However, the underlying physiological, behavioural and genetic mechanisms are largely unknown (Hall, 2004; McManus *et al*., 2008). As milk yield in dairy cattle has risen, and growth rates and leanness in pigs and poultry have increased, the animals' metabolic heat production has increased and their capacity to tolerate elevated temperatures has declined (Zumbach *et al*., 2008; Dikmen and Hansen, 2009). Long-term single-trait selection for yields has, thus, given rise to animals with lower heat tolerance.

Measurement of the effects of heat stress is difficult. Its effects on milk yield at specific test days are more immediate and easier to measure than those on growth (Zumbach *et al*., 2008). Although a considerable amount of research into the heat tolerance of different species was undertaken during the 1970s and 1980s, there is currently a lack of experimentation and simulation of livestock physiology and adaptation to climatic extremes. This makes it difficult to predict impacts and develop adaptation strategies.

In addition to standard physiological measures of heat stress, such as rectal temperature and heart and respiratory rates, evaluating the implications of heat stress in extensive grazing systems also requires measurement of net radiation and convection (Howden and Turnpenny, 1998). Heat tolerance tests will give misleading results unless modifying factors such as age, nutrition, state of health, reproduction and emotion, physical activity, level of production, acclimatization and management are taken into consideration (Bianca, 1961). However, research into behavioural or metabolic differences among breeds is in its infancy.

A number of studies have revealed differences in heat tolerance among different cattle breeds and crosses (e.g. Turner, 1975; Amakiri and Funsho 1979; Lemerle and Goddard, 1986; Singh and Bhattacharyya, 1990; Burns *et al*., 1997; Prayaga *et al*., 2006). Tropical breeds tend to have better heat tolerance than those from temperate zones. However, research has focused on a limited number of breeds. In chickens, several studies comparing the heat tolerance of birds with different types of feathering have been undertaken. Both “naked-neck” and “frizzle-feathered” chickens have been found to cope better with high temperatures than their normally feathered counterparts (Horst, 1988; Mathur and Horst, 1990; Cahaner *et al.*, 1993). Few comparative studies of heat tolerance have been undertaken in other livestock species.

Resistance and tolerance to diseases and parasites

The existence of breeds that are more resistant or tolerant than others to particular diseases is well established, although the number of breeds and diseases that have been subject to scientific study is quite limited and the underlying physiological and genetic mechanisms are not well understood. The topic has been reviewed in a number of publications in recent years (Axford *et al.*, 2000; FAO, 2002; FAO, 2007a; FAO, 2009e; FAO, 2010d) and is therefore not discussed in detail here.

In addition to the role that genetic resistance or tolerance can play in protecting individual animals from the effects of disease, genetic diversity at the level of the population may influence the dynamics of pathogen transmission. The so-called “dilution effect” – lower infection rates in highly species-diverse host communities because the presence of unsuitable hosts lowers the infection rates among vectors – has been demonstrated in a number of vector-borne diseases (Morand and Guégan, 2008). At the level of within-species genetic diversity, mathematical models indicate that high levels of genetic diversity within populations reduces the probability of catastrophic epidemics, while increasing the probability of minor epidemics (Springbett *et al.*, 2003).

Feeding and nutritional adaptations

The different feeding capacities and habits of different types of animal are essential in enabling the livestock sector as a whole to utilize a wide range of feed resources, many of which are unsuitable for direct consumption by humans. At the species level, the big divide in nutritional terms is between ruminant and monogastric animals. The former are adapted to forage-based diets, i.e. they can convert grasses and other fibrous plant materials that are inedible to humans into meat, eggs, milk and other products (camelids are not “true” ruminants but their digestive systems have similar adaptations). Among monogastrics, “hind-gut fermentors” such as horses and rabbits are relatively efficient digesters of fibrous feeds, but other species such as chickens and pigs need diets that are lower in fibre and closer to those of humans.

Different ruminant and camelid species have different feeding habits and tend to utilize different types of vegetation. For example, goats and camels make more use of browse (shrubs and trees) than do sheep and cattle. Goats from dry areas tend to be better able than sheep and cattle to detoxify the tannins found in the leaves of trees and shrubs (Silakanove, 1997). Goats also have the advantages of being able to rear up on their hind legs, climbing well and having mobile upper lips and prehensile tongues that enable them to pluck leaves from thorny shrubs and select the most nutritious parts of the plant (Huston, 1978; Narjisse, 1991; Barroso *et al.*, 1995). Keeping browsing animals has certain advantages when feed is in short supply as they make use of forage that cannot easily be used by other species – i.e. there is a degree of complementarity if grazing and browsing animals are kept together – and because shrubs tend to provide a source of green forage during the dry season.

Within species, there are also differences in the capacity of different breeds to utilize particular kinds of feed. For example, Blench (1999) reports that the Sokoto Gudali cattle of West Africa specialize in eating browse and will feed on woody material that other breeds find very unpalatable. Among cattle in general, zebu (*Bos indicus*) breeds tend to deal better with low-quality forage than do taurine (*Bos taurus*) breeds, while the latter have better feed conversion ratios when fed on high-quality feed (Albuquerque *et al.*, 2006). In the case of goats, a study in Spain indicated that the Celtiberic breed selected a more browse-based diet than Cashmere goats (Jauregui *et al.*, 2008). Similarly, a study in Mexico found Granadina goats to be better adapted than Nubian goats to feeding on the shrubby vegetation of the Chihuahuan Desert (Mellado *et al*., 2004). Silanikove (1997) reports that the Black Bedouin goat is better able than the Saanen to digest high-fibre forages. The desert goats were also better at maintaining their body weights on very low energy diets, apparently by lowering their metabolic rates (Silanikove, 1986). The ability to survive extended periods of feed shortage is essential for animals kept in drought prone areas. Silanikove (1986) cites further studies that showed similar capabilities in llamas and African zebu cattle. Some breeds from temperate regions also have unique dietary adaptations. For example, the North Ronaldsay sheep, which grazes the shoreline of an island off the coast of Scotland, is adapted to a diet containing a large amount of seaweed (Woolliams *et al*., 2008).

Grazing and browsing animals not only have to be able to thrive on the diet provided by the local vegetation, but also have to be able to cope with the other challenges that they encounter as they feed: heat, cold, rain, snow, ice, wind, steep or rough terrain, waterlogged ground, parasites, predators and so on. Moreover, they may need to walk long distances and go for long periods without drinking in order to access forage over a wide area of rangeland. When pastoralists are asked about their breed preferences and criteria for breeding decisions, characteristics related to grazing ability are often mentioned (FAO, 2007a; FAO/WAAP, 2008a; Krätli, 2008; FAO, 2009a). As discussed in Section B, many of the hazards encountered by grazing animals are potentially exacerbated by climate change.

Comparative studies of characteristics linked to grazing ability are rare. However, as noted above, a number of breeds have been shown to possess superior resistance or tolerance to specific diseases or parasites. In many cases, such adaptations enable these breeds to graze in areas that are unsuitable for other animals. For example, several studies have shown the superior ability of dryland breeds such as the Black Bedouin goat (Shkolnik, 1980), Black Moroccan goat (Hossaini Hillaii and Benlamlih, 1995) and Black Headed Persian sheep (Schoenman and Visser, 1995) to cope with water shortages and hence graze over a wide area. Similarly, resistant or tolerant breeds are better able than other animals to utilize grazing lands that are infested with parasites or disease vectors. Camels are well known for having a range of morphological, physiological and behavioural characteristics that enable them to move around in the desert. For example, experiments have shown that dromedaries can maintain feed intake and digestion in the face of high temperatures and restricted access to water (Guerouali and Wardeh, 1998). The ability of Kuri cattle to tolerate insect bites enables them to remain close to Lake Chad during the rainy season when other cattle have to leave the area (Blench, 1999). Likewise, the Chilika buffalo is the only breed that can cope with the high humidity and lack of non-saline drinking water that characterize its home production environment on the shores of Chilika Lake in eastern India (FAO, 2010e). The Garole sheep of the Sunderban region of India and Bangladesh, which is noted for its ability to graze while standing knee-deep in water, provides another example (Sharma *et al*., 1999; Nimbkar, 2002).

Confined animals have fewer problems to contend with as they feed, but may, for example, have to be sufficiently heat tolerant to maintain their feed intakes in the face of high ambient temperatures and the heat generated by digesting poor quality forage diets. As discussed above, such abilities tend to be found to a greater extent in tropical than in temperate breeds.

Moving animal genetic resources as part of climate change adaptation strategies

One option for adapting production systems to the effects of climate change is to bring in AnGR that are better adapted to the changed conditions. These animals are likely to come from production environments where for many years they have been exposed to environmental conditions similar to those now prevailing in the areas to which they are being introduced. If climate change leads to major changes in local agro-ecosystems, at a rate that outstrips the capacity of livestock and their keepers to adapt, such shifts in breed distribution may become increasingly necessary and frequent. Currently, however, the dominant pattern of gene flow on a global scale does not focus on the movement of locally adapted animals into equivalent agro-ecological zones, but on the movement of high-output breeds that need highly controlled production environments. The majority of this gene flow is between the countries of the developed “North” and from the North to the developing “South”. The main exception to this pattern during the last hundred years or so has been the movement of tropically adapted cattle from South Asia to Latin America. There have also been some introductions of grazing animals from the South into the hotter parts of developed countries such as Australia and the United States of America (FAO, 2007a).

On a more local scale, as noted in Section B, species and breed substitution has already occurred in some production systems that have been badly affected by droughts in recent decades (Blench, 1999). Traditional livestock keepers are often interested in experimenting with new breeds and introducing new blood to their herds (FAO, 2009a; FAO/WAAP, 2008a). Mechanisms of this kind have probably contributed to the climate-related shifts in AnGR distribution that have occurred to date, and will probably have an important role to play in the future, provided the relevant local knowledge and breeding expertise is retained and no constraints to accessing the relevant AnGR arise. However, if climate change leads to very substantial and rapid changes in local production environments, existing mechanisms for adjusting AnGR portfolios may no longer be sufficient. If this happens, it may be necessary to facilitate livestock keepers' access to alternative AnGR and to information on their characteristics and potential utility in climate-change adaptation. Any advice offered on the suitability of breeds for introduction to new areas should, clearly, be as accurate and relevant as possible. This, however, is made difficult by the paucity of information available on the adaptive characteristics of specific breeds or on their performance in diverse production environments. As described above, where studies of adaptive characteristics have been undertaken, they normally focus on a single trait (resistance to a specific disease, heat tolerance, etc.). The suitability of a breed for introduction to a new area requires adaptation not only to a single environmental challenge, but to the range of challenges prevalent in the target area and to the various uses to which the animals will be put by their new keepers. Identifying breeds with good potential for introduction to a given production environment is therefore a complicated task. One way of obtaining a proxy indication of suitability is to compare the candidate breeds' home production environments to those in the area targeted for introduction. If the breeds have been present in their current production environments for a long period, they are likely to have acquired genetic adaptations to the prevailing conditions and therefore to be good candidates for introduction to similar production environments elsewhere. Such an approach requires good knowledge of the production environments at both ends of the potential transfer (see further discussion below in the subsection on characterization).

If development agencies are contemplating introducing a breed into a new area in response to climate change, it is essential that livestock keepers are properly consulted as part of a thorough assessment of the breed's suitability for use in the current and projected future production environment. If the introduction of high-output breeds is being contemplated, the potential future effects of climate change on the local production environment underline the importance of such assessments. Detailed advice on how to conduct assessments of production systems and their trends, and on matching breeds to livestock development objectives and strategies can be found in FAO (2010e).

Another point that should be noted in the context of introducing adapted breeds to new areas is that differences in animals capacities to thrive in harsh conditions – particularly their feeding behaviour – are not merely matters of genetics but also of learning. Young animals learn from their mothers and other members of the herd or flock (Provenza and Burritt, 1991; Glasser *et al*., 2009) and in some cases livestock keepers' use specific management practices to promote the development of desirable feeding behaviours among their animals (Krätli, 2008). This is one reason why it is important to maintain AnGR *in situ* in functioning production systems rather than in *ex situ* collections.

If international movements of AnGR are required in response to climate change, legal frameworks affecting the import and export of genetic material will come into play. The most likely development, at least in the short term, is probably greater demand for exchange of AnGR among neighbouring countries (or those in neighbouring latitudes) that have roughly similar production environments. However, it has been suggested that climate change may contribute to a shift in the current dominant pattern of gene flow, with greater demand for genetic material from breeds originating from hotter parts of the world and possibly greater gene flow from South to North. The extent to which such a scenario is likely to be realized is not yet clear (Hiemstra *et al*., 2006; FAO, 2009e). As long as the industrial production systems of the developed world remain economically and socially viable, they can do a lot to isolate their animals from the effects of climate change and thereby continue using the same breeds as they do today. Introduction of new types of adapted AnGR may be more likely in the extensive grazing systems of developed countries such as Australia and the United States of America. However, even if a breed has a desirable climate change-relevant adaptation, its more widespread use internationally is far from certain. Blackburn and Gollin (2008) emphasize that successful introduction of new breeds into the United States of America has been based on several production traits and has required the interest and acceptance of the private sector, while introduction to take advantage of single traits has not proved sustainable, especially when other economically important traits were compromised. Breed replacement may involve considerable costs and substantial investments in learning and gaining experience.

To date, large production differentials have meant that commercial breeders in developed countries have made little use of genetic material from breeds from developing countries (or from conserved breeds and lines from developed countries). Moves towards genomic selection, which will allow better use to be made of the genetic variation present in commercial populations, will further weigh against the use of alternative sources of genetic material (Hill and Xhang, 2008). Whatever the circumstances, it can be expected that only well-characterized breeds will be used for targeted crossing or gene insertion to increase the adaptedness of high-output breeds. Most breeds from developing countries have not been subject to thorough phenotypic and genetic characterization studies and, unless this is remedied, they are unlikely to be utilized in such programmes.

There is a general perception that international trade in AnGR operates relatively smoothly, with the main restrictions being related to zoosanitary requirements (Hiemstra *et al*., 2006; FAO, 2009e). However, some stakeholders have expressed concerns regarding the possibility that access and benefit sharing regulations that do not account for the specific needs of the AnGR sector may create unnecessary barriers. There are also concerns in some quarters regarding the prospect of imported AnGR being utilized without equitable sharing of benefits with the countries and the livestock-keeping communities who developed these resources (Hiemstra *et al*., 2006; FAO, 2009e).

The implications of the *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization* (CBD, 2011)*,* adopted in October 2010, for the exchange of AnGR are not yet clear. In its preamble, the protocol recognizes "the special nature of agricultural biodiversity, its distinctive features and problems needing distinctive solutions" and "the interdependence of all countries with regard to genetic resources for food and agriculture as well as their special nature and importance for achieving food security worldwide and for sustainable development of agriculture in the context of poverty alleviation and climate change ..." To date, there has been no strong push towards the development of a legally binding international instrument specifically for the exchange of AnGR. The report of an international technical expert workshop[9] on access and benefit sharing of AnGR, held in Wageningen, the Netherlands, in December 2010, argues that such a framework is not a "first choice" at present (Hiemstra *et al*., 2010) principally because of biological, technical and institutional differences between the AnGR and plant genetic resources sectors; the relatively few problems encountered in international exchange of AnGR, and the large investments that would be required in negotiating a legally binding agreement. However, the need to monitor developments in the wake of the adoption of the Nagoya Protocol was recognized (ibid). The expert workshop was more enthusiastic about the idea of voluntary instruments, such as the development of guidelines that could be used by national governments when developing measures related to the international exchange of AnGR, model material transfer agreements (see also FAO, 2005; Tvedt *et al*., 2007; Correa, 2010), biocultural protocols (see also UNDP/Natural Justice, 2009; LPP *et al*., 2010) and greater attention to livestock keepers' rights (see also Life Network, 2009; Köhler-Rollefson *et al*., 2010). On the importing side, some countries have already introduced

[9] http://www.cgn.wur.nl/UK/CGN%20General%20Information/Education%20and%20information/Seminars/

requirements for so-called genetic impact assessments as a means of preventing the introduction of AnGR that are poorly suited to local production systems (Tvedt *et al.*, 2007; Pilling, 2008).

The various measures and proposals discussed in the preceding paragraph have not been motivated specifically by the need to address the impacts of climate change. Nonetheless, many of the topics addressed – effective use of local AnGR and local knowledge, ensuring good match between introduced breeds and their new production environments, supporting livestock-keeping communities, and promoting fair and equitable access and benefit sharing – are highly relevant to climate-change adaptation.

Whether or not climate change leads to greater demand for international transfer of adapted AnGR for immediate deployment in production, it is a factor motivating interest in greater international collaboration in characterization and conservation activities – and potentially in international exchange of genetic material for gene-banking purposes. It is important that international collaboration in such efforts is not undermined by concerns over access and benefit sharing. The issue was taken up at the Sixth Session of the Intergovernmental Technical Working Group on Animal Genetic Resources for Food and Agriculture, which recommended that the CGRFA:

> *"invite FAO and countries to initiate the development of policies and protocols for exchange of animal genetics resources for the purpose of multi-country conservation activities, including gene banking, especially in light of spreading diseases, climate change and natural disasters, for review by the Working Group"* (FAO, 2010e).

Selective breeding

As discussed in Section B, projections suggest that climate change will, in places, lead to temperature rises that affect livestock productivity and exceed producers' capacities to minimize heat stress in their animals by adjusting management methods. It is therefore likely that further genetic selection for effective thermoregulatory control will be needed. This calls for the inclusion of traits associated with thermal tolerance in breeding indices, and more consideration of genotype-by-environment (G × E) interactions. Correlations between the performance of genotypes in different environments are lower in hot countries, suggesting that heat stress plays an important role in G × E (Zwald *et al.*, 2003).

There appears to be some scope for breeding to improve heat tolerance. Studies in Brazil have shown that various physiological and blood parameters differ between local and exotic cattle breeds (McManus *et al.*, 2008). Several Latin American cattle breeds with very short, sleek, hair coats have been observed to maintain lower rectal temperatures; research on the "slick hair" gene, a major gene which is dominant in inheritance and located on Bovine Chromosome 20, is ongoing (Olson *et al.*, 2003; Dikmen et *al.*, 2008). Collier *et al.* (2008) suggest that there is some potential for improving heat tolerance through manipulation of genetic mechanisms at cellular level.

Selection for heat tolerance in high-output breeds based on rectal temperature measurements and inclusion of a temperature-humidity index (THI) in genetic evaluation models are promising approaches. Parameters such as THI or dry-bulb temperature measurements are used as indicators of heat stress (Finocchiaro *et al.*, 2005; Bohmanova *et al.*, 2007; Dikmen and Hansen, 2009). However, in the dairy sector it may be difficult to combine adaptation to high-temperature environments with high production potential. Different physiological and metabolic processes seem to control heat tolerance and milk yield on the one hand, and heat tolerance and reproductive performance on the other (Ravagnolo and Misztal, 2002; Bohmanova *et al.*, 2005, 2007). In beef cattle, the genetic antagonisms between adaptation to high-temperature environments and high production potential seem to be more limited than those in dairy cattle. Improved characterization of adaptive traits, use of reproductive technologies and molecular markers, and strategic cross-breeding are being incorporated into breeding programmes: for example, at the Australian Beef Cooperative Research Centre (Prayaga *et al.*, 2006).

Improving disease resistance through selective breeding is another potential component of climate change-adaptation strategies. As discussed in Section B, the precise effects of climate change on disease distribution and impact are difficult to predict. It is, therefore, difficult to predict the extent to which climate change will increase the need to include disease resistance in selection indices. The perception among experts in the field appears to be that climate change will increase interest in the use of genetics in disease control strategies because it will create favourable environmental conditions for the spread of some diseases (FAO, 2010d). Individual breeders' willingness to become involved in breeding for resistance depends very much on whether alternative control methods (drugs, vaccinations, vector control, etc.) are effective and easily available, and this means that in the case of many pathogens interest is limited at present (ibid.). Nonetheless, the numerous problems that have been encountered with the sustainability of such methods, particularly the development of resistance to chemical treatments among pathogens and disease vectors, point to the long-term significance of genetic approaches to disease control. Some health problems such as gastro-intestinal nematodes (whose distribution is much affected by the climate) and mastitis are already addressed in commercial breeding programmes in developed countries (FAO, 2007a; FAO, 2010d). Interest in breeding for resistance to blowfly strike – another problem influenced by the climate – is increasing in countries such as Australia and New Zealand as problems with other control methods accumulate (FAO. 2010g).

In developing countries, access to (or affordability of) veterinary inputs and services are problems for many livestock keepers, who therefore rely heavily on the adaptedness of their animals to disease and parasite challenge. However, structured breeding programmes are difficult to organize in such circumstances (FAO, 2007a; FAO, 2010e). Priority diseases and parasites for research on genetic resistance in developing countries include gastro-intestinal nematodes, trypanosomiasis, ticks and tick-borne diseases including the various forms of theileriosis (FAO, 2010d). All are potentially affected by climate change.

Selecting for production traits and production efficiency decreases (other things being equal) the quantity of greenhouse gases produced per unit of output. Selection that promotes longevity, fertility or early maturity can also contribute to this effect. Several studies have investigated the contributions that genetic improvement programmes have made, or could make, to reducing greenhouse gas emissions. Based on a life-cycle analysis, Jones *et al.* (2008) estimated that during the period from 1987 to 2008, annual reduction in greenhouse gas emissions in the United Kingdom achieved through genetic improvement ranged from 0.8 percent in pigs and dairy cattle to 1.2 percent and 1.3 percent in broilers and layers, respectively. The largest contribution in broilers came from improved feed conversion ratio and in pigs from improvements to growth rate and fertility (ibid.). Rowlinson (2008) calculated that in the United Kingdom, it would be possible to reduce methane emissions from dairy production by 3 percent by improving the lifespan of dairy cows from 3.02 to 3.5 lactations. Similarly, Garnsworthy (2004) calculated that if cow fertility had been restored from the level in 2003 to that in 1995, methane emissions from the British diary industry would have been between 10 and 15 percent lower than they were. Capper *et al.* (2009) report that genetic gain in milk performance has considerably reduced the greenhouse gas emissions of diary production in the United Sates of America.

In ruminants, there is sufficient genetic variability in feed intake – independent of live weight and daily gain – to permit selection for this trait (Flachowsky and Brade, 2007). The Australian beef industry now includes net feed efficiency as an integral part of its breeding programme.[10] Alford *et al.* (2006) calculated that methane emissions could be reduced by up to 16 percent in 25 years if residual feed intake[11] were included in beef selection programmes in Australia. Hayes *et al.* (2009), based on

[10] http://www.beefcrc.com.au/

[11] Residual feed intake is the difference between an animal's actual feed intake and the feed intake expected given the size of the animal and the growth rate it achieves. Genetic selection to reduce residual feed intake can result in progeny that eat less without sacrificing growth or production performance (Sainz and Paulino, 1998). However, the costs of identifying individuals with good residual feed intakes are high, particularly in grazing production systems.

the assumption that future dairy systems in Australia will become more reliant on pasture and less on grain, proposed selecting sires whose daughters will cope better with low feeding levels and higher heat stress. Markers associated with sensitivity of milk production to feeding level and sensitivity of milk production to temperature–humidity index in Jerseys and Holsteins were identified (ibid). Because of the influence of feed quality on methane emissions from rumen fermentation, productivity improvements in pasture-fed ruminants in the tropics will result in larger proportional reductions in methane emissions per animal than would be achieved by the equivalent productivity improvements in ruminants grazing more digestible temperate pastures (McCrabb and Hunter, 1999). Possible synergies between plant and animal breeding should be investigated (FAO, 2008b). Future options for selection in ruminants lie in the host components of rumen function, in post-absorption nutrient utilization and in disease resistance. In pigs and poultry, genetic variation in digestion parameters can be exploited (Warkup, 2007).

Conservation

Future utilization of AnGR in climate change adaptation, or for other purposes, requires that the relevant resources have not been lost. Approximately 22 percent of breeds recorded in the Global Databank on Animal Genetic Resources[12] are classified as being at risk of extinction and another 38 percent are of unknown risk status (FAO, 2010h). Numerous threats to AnGR diversity have been identified (Gibson *et al*., 2006; FA0, 2007a; FAO, 2009b; Pilling, 2010). As discussed in Section B, some of these threats are likely to be intensified by climate change. The *Global Plan of Action for Animal Genetic Resources* (FAO, 2007b) recognizes the significance of climate change and the need for conservation programmes and strategies to account both for gradual environmental changes in livestock production systems and the effects of disasters and emergencies.

The prospect that climate change will bring more frequent catastrophes and major disruptions to livestock production probably increases the significance of establishing back-up *ex situ* collections of AnGR and the importance of situating these collections in dispersed locations. The *Global Plan of Action* recognizes that global or regional facilities may play a role in *ex situ* conservation. Many stakeholders express support for the idea of their countries' participation in such endeavours, with regional initiatives being the most popular option (FAO, 2010c). However, few if any multicountry gene banks have been established. As noted above, the development of policies and protocols that facilitate international exchange of AnGR for conservation may help to overcome this lack of progress (FAO, 2010f), but financial and logistical constraints also need to be addressed (FAO, 2010c).

The basic arguments in favour of *in situ* approaches to conservation of AnGR – that genetic adaptations to harsh local conditions and links between AnGR and local livestock-keeping knowledge are maintained, and that AnGR can continue to co-evolve with their production environments – remain valid in the context of climate change. However, *in situ* conservation strategies need to take into account the effects of climate change in breeds' production systems of origin and the possibility that breeds may no longer be so well adapted to the conditions prevailing in their geographical home zones.

Draft guidelines on cryoconservation of AnGR have been prepared by FAO as part of a series of publications in support of countries implementation of the *Global Plan of Action* (FAO, 2010i). Guidelines on *in situ* conservation are in preparation.

Characterization

Effective management of AnGR diversity in the face of climate change requires sound knowledge of these resources and the production environments (broadly defined to include management and social factors as well as the "natural" environment) in which they are kept. As discussed above, if the

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[12] Backbone of the Domestic Animal Diversity Information System (DAD-IS: http://www.fao.org/dad-is).

introduction of particular breeds or species to new locations is being considered as part of climate change adaptation measures, it is important that the match between these AnGR and the production environments in their potential new homes is well understood, taking both the adaptive and the production traits of the animals into account. Breeding programmes that aim to improve the adaptedness of livestock populations to their production environments require good knowledge of the relevant characteristics in the targeted populations. Assessments of the risk posed to AnGR by climatic and other disasters require knowledge of the geographical distribution of breeds and populations. Prioritization and planning of conservation programmes and measures to promote sustainable use of AnGR require knowledge of the respective breeds and of their production environments, demographics and geographical distributions.

As discussed above, characterizing the production environment to which a breed has been exposed for a substantial period of time is a means of obtaining a proxy indication of its adaptive characteristics. This is another reason why it is important for characterization studies to focus not only on the animals themselves but also on their production environments (FAO/WAAP, 2008b; FAO, 2010j). A module for recording descriptions of breeds' production environments in the Domestic Animal Diversity Information System (http://www.fao.org/dad-is) has been developed. The module includes a tool for mapping breed distributions, which can be overlaid with digitized maps of other aspects of the production environment.

The *Global Plan of Action* calls for the development of international technical standards and protocols for characterization. The prospect that climate change-adaptation measures may require more frequent introduction of breeds into new geographical areas underlines the importance of comparability in the outputs of characterization studies and of ensuring that they are made widely available. The development of common data formats for phenotypic characterization studies is an important priority in this respect.

Detailed advice on phenotypic and molecular characterization and on surveying and monitoring of AnGR is provided in the respective draft FAO guidelines (FAO, 2010j, 2010k, 2010l). Ideally, such studies and surveys should be part of cohesive national strategies addressing countries' needs for AnGR-related data and information. The potential effects of climate change should be taken into account in the development of such strategies, both in terms of the information targeted and in terms of the frequency with which monitoring surveys need to be repeated (FAO, 2010l).

IV. CONCLUSIONS

Climate change is likely to affect livestock production systems and the associated AnGR in a number of ways, presenting many challenges both to the livestock sector as a whole and to the more specific field of AnGR management. However, in the field of AnGR management, much of the basic information needed for planning and implementing effective climate change adaptation and mitigation measures remains unavailable. Implementing Strategic Priority Area 1 of the *Global Plan of Action* – "Characterization, inventory and monitoring of trends and associated risks" – is therefore fundamental. In the context of climate change, the importance of research into breeds' adaptive traits and characterization of their production environments should be underlined.

Despite numerous extinctions and substantial genetic erosion among locally adapted breeds, the world's livestock production systems remain home to many species and breeds of livestock that are well adapted to coping with harsh environmental conditions. These *in situ* resources represent the main reservoir of livestock genetic diversity upon which future climate-change adaptation and mitigation strategies will depend. *Ex situ* collections are patchy, particularly in developing countries, which is where many of the breeds with good capacity to cope with the agro-ecological impacts of climate change are located.

Capacity to control the production environment through the use of housing, temperature control, purchased feed and veterinary technologies means that the operators of "industrial" livestock production systems may be able to adapt relatively easily with the biophysical effects of climate change at the local level. However, they may not be immune to its economic effects, particularly if combined with other factors that drive up input costs. Traditional production systems tend to have the advantage of keeping animals that are well adapted to harsh conditions and that can thrive without the use of expensive inputs. In many such systems, the livestock keepers are also experienced in dealing with extreme and fluctuating environmental conditions. Nonetheless, their reliance on local natural resources makes them vulnerable to problems such as declining availability of forage or the appearance of unfamiliar diseases or parasites. Traditional systems are often already under a variety of pressures, many of which may be exacerbated by climate change. Many livestock keepers are poor and lack the financial and other livelihood resources that could help them in adapting to climate change (FAO, 2010a). Production systems in which non-locally adapted livestock have been introduced without the accompanying developments needed to support such animals, or where the supply of external inputs is precarious, may be vulnerable to many of the direct and indirect effects of climate change.

Many of the challenges that climate change poses for the management of AnGR are not qualitatively different from those that would exist in a more stable climate. Problems such as feed shortages, heat stress, and disease and parasite challenge may become more intense and new areas may be affected. Additional breeds may be faced with the risk of extinction as their production systems are disrupted, creating the need for additional conservation measures. More frequent disasters may increase the importance of establishing dispersed *ex situ* collections. The need for good information on the characteristics of breeds and their production environments is likely to increase. Additional circumspection in the assessment of production systems and future trends may be required if the introduction of non-locally adapted breeds to a new area is contemplated. Breeders may need to reassess the balance between production and adaptation in setting breeding objectives. It will be important to raise awareness among stakeholders involved in planning and implementing climate change adaptation and mitigation activities of potential uses of AnGR and potential threats to genetic diversity. The roles of livestock keepers as custodians of locally adapted AnGR and their potential roles in climate change adaptation and mitigation will need to be recognized and supported.

Perhaps the most distinct new challenge associated with climate change is the potential for rapid agroclimatic changes that outstrip the capacity of AnGR to adapt to changes in their home production environments. If this happens, the issues of how to match breeds and production environments, and manage shifts in breed distribution may become much more pressing. Conservation strategies may need to be adapted to account for situations in which the establishment of *in situ* schemes within breeds' geographical areas of origin becomes problematic because the local production environments are no longer well suited for maintaining the breeds. Modelling may be useful in predicting where such problems may arise. However, monitoring and early-warning systems – both for the size and structure of breed populations and for changes in production environments – will also be essential.

Shifts in breed and species distribution in response to changing climate have probably already occurred on a limited scale. However, the overall pattern of international gene flow has, to date, been little affected by climate change. It is unclear whether and to what extent this will change in the future and whether this will have any implications for related policy and legal frameworks. A more immediate concern may be to ensure that progress towards better international collaboration in characterization and conservation efforts – important objectives in the context of climate change and the threat of more frequent climatic disasters – is not stalled by unnecessary barriers to exchange or a lack of confidence in regulatory provisions.

By the time the *Global Plan of Action for Animal Genetic Resources* was adopted in 2007, climate change had been widely recognized as a major challenge for agriculture, food security and for humanity as a whole. *The Fourth Assessment Report of the Intergovernmental Panel on Climate Change* was released in the same year, and both the *Interlaken Declaration on Animal Genetic Resources* and the preamble to the *Global Plan of Action* emphasize the links between AnGR management and climate change. Some four years later, the case for implementing the *Global Plan of*

Action, and for its relevance to climate change adaptation and mitigation, remains strong. Effective implementation of the *Global Plan of Action* would be an important step towards improving the capacity of the AnGR sector, and the livestock sector more broadly, to respond to climate change – knowledge, availability (sustainable use, conservation and exchange) and strategies for use and development of AnGR would all be strengthened. While few aspects of improved AnGR management are relevant only in the context of climate change, certain policy and management measures stand out as being particularly significant. These include the following (grouped according their relevance to the four strategic priority areas of the *Global Plan of Action*):

Strategic priority area 1. Characterization, inventory and monitoring of trends and associated risks

- developing methods for characterizing adaptive traits relevant to climate-change adaptation (heat tolerance, disease resistance, adaptation to poor diets, etc.) and for comprehensive evaluation of performance and use of animals in specific production environments and describing these production environments in a standard way;
- incorporating the above techniques into phenotypic characterization studies and AnGR surveys;
- improving knowledge and awareness of, and respect for, local and indigenous knowledge relevant to climate-change adaptation and mitigation;
- identifying potential climate change-related threats to specific AnGR, ensuring that long-term threats (e.g. gradual environmental changes) are monitored and that urgent action is taken to address immediate threats (e.g. small populations at severe risk from climatic disasters);
- exploring the possibility of modelling the future distribution and characteristics of production environments, to support the assessment of threats and the identification of areas that may be suitable for particular breeds in the future;
- improving knowledge of breeds' current geographical distributions to support the above actions and to facilitate planning of climate-change adaptation measures and AnGR conservation strategies;
- improving the availability of the above-described knowledge, including via DAD-IS and other AnGR information systems;
- ensuring that monitoring strategies and early-warning systems for AnGR are sensitive to climate-change-related trends and risks;

Strategic priority area 2. Sustainable use and development

- ensuring that AnGR management planning is integrated into the planning of climate-change adaptation and mitigation measures at the level of the production system and nationally;
- exploring options for increasing carbon sequestration in pastureland through better grazing management, the role of AnGR in such measures, and the potential that they may offer for integrated approaches to climate-change mitigation, livelihood objectives, conservation of wild biodiversity and sustainable use of AnGR;
- strengthening cooperation among the international forums and organizations involved in AnGR management, other aspects of biodiversity, climate change adaptation and mitigation, and other environmental issues;
- ensuring that livestock keepers and other relevant stakeholders are involved in planning climate-change adaptation and mitigation measures within livestock production systems and the role of AnGR within these measures;
- building on, or integrating, local knowledge of how to cope with harsh and fluctuating production environments within climate-change adaptation strategies (as relevant and appropriate to future conditions and objectives);

- ensuring that plans to introduce breeds to new geographical areas take account of climatic and other agro-ecological conditions and their predicted future trends;
- reviewing and, if necessary, adapting breeding goals to account for the effects of climate change;
- improving access to inputs and livestock services relevant to climate-change adaptation;
- exploring the potential for the introduction of payments for environmental services as a means of promoting ecological and socio-economic sustainability in grazing systems and hence the maintenance of the associated AnGR;

Strategic Priority Area 3. Conservation

- ensuring that conservation strategies account for the observed and projected effects of climate change, including agro-ecological changes and disaster risk, and if relevant the effects of climate change mitigation policies;
- reviewing *in situ* conservation schemes to account for climate change-driven changes in the home production systems of the respective breeds;
- ensuring that *ex situ* collections are sufficiently comprehensive, well managed and well located to provide insurance against climatic and other disasters;

Strategic Priority Area 4. Policies, institutions and capacity-building

- promoting awareness among policy-makers of the potential roles of AnGR in climate change adaptation and mitigation;
- ensuring that national strategies and action plans for AnGR account for the effects of climate change and can be reviewed and amended as necessary to account for future climate-related developments;
- promoting exchange of information on climate-change adaptation strategies for livestock systems and AnGR management, relevant breed adaptations and breed performance in specified production environments; and
- facilitating transparent, fair and equitable access to AnGR needed for climate change adaptation along with relevant associated knowledge and technologies.

The overall implications of climate change for the livestock sector and for AnGR diversity are not easy to predict. In many ways, climate change reinforces already existing trends, counter trends and complexities arising from the interplay of socio-economic, technological, policy and environmental drivers (FAO, 2007a; FAO 2010a). The immediate effects of additional climate-related problems, and of mitigation efforts, will often be to increase the competitive advantages of large-scale industrial production and thus exacerbate the growing dichotomy within the livestock sector between such systems and the mass of increasingly marginalized smallholders and pastoralists. Climate change is likely to increase the importance of genetically well-adapted livestock in many production systems where the animals cannot be isolated from the local environment. This is likely to be particularly the case for poorer livestock keepers in marginal areas where conditions are harsh and external inputs are difficult to obtain, but may also have implications for grazing systems in more developed areas and for small-scale producers seeking to move towards more commercial production. Even for the most technologically advanced production systems, climate change is an additional source of uncertainty – and potential threat – particularly in combination with other factors that undermine their sustainability. Thus, climate change underlines the importance both of ensuring good ongoing matches between AnGR and their production environments and of maintaining the diversity needed for adapting to future challenges.

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