



## Review

# The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know

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## ABSTRACT

Despite the importance of livestock to poor people and the magnitude of the changes that are likely to befall livestock systems, the intersection of climate change and livestock in developing countries is a relatively neglected research area. Little is known about the interactions of climate and increasing climate variability with other drivers of change in livestock systems and in broader development trends. In many places in the tropics and subtropics, livestock systems are changing rapidly, and the spatial heterogeneity of household response to change may be very large. While opportunities may exist for some households to take advantage of more conducive rangeland and cropping conditions, for example, the changes projected will pose serious problems for many other households. We briefly review the literature on climate change impacts on livestock and livestock systems in developing countries, and identify some key knowledge and data gaps. We also list some of the broad researchable issues associated with how smallholders and pastoralists might respond to climate change. The agendas of research and development organisations may need adjustment if the needs of vulnerable livestock keepers in the coming decades are to be met effectively.

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## 1. Introduction

Livestock systems in developing countries are changing rapidly in response to a variety of drivers. Globally, human population is expected to increase from around 6.5 billion today to 9.2 billion by 2050. More than 1 billion of this increase will occur in Africa. Rapid urbanisation is expected to continue in developing countries, and the global demand for livestock products will continue to increase significantly in the coming decades (Delgado et al., 1999). The potential impact of these drivers of change on livestock systems and the resource-poor people who depend on them for their livelihoods is considerable. These impacts will be influenced by both supply-side shifts in natural resource use as well as market-led demand changes. Given the complexity of livestock (and in most cases crop–livestock) systems in developing countries, a mix of technological, policy and institutional innovations will be required. On the technology side, improvements will be linked to a combination of feed and nutrition, genetics and breeding, health and environmental management options, with different combinations appropriate to different systems.

At the same time, the climate is changing. Significant changes in physical and biological systems have already occurred on all continents and in most oceans, and most of these changes are in the direction expected with warming temperature (Rosenzweig et al., 2008). For the future, there is considerable uncertainty, but recent “best estimates” of temperature increases from the IPCC in the Fourth Assessment Report (AR4) are in the range 1.8–4 °C in 2090–2099 relative to 1980–1999, depending on the scenario of future greenhouse-gas emissions that is used to drive the climate models (IPCC, 2007). The impacts of temperature increases at even the lower end of this range will be far-reaching. At the lower end of the range of temperature rise (1–3 °C), global food production might actually increase but above this range would probably decrease (IPCC, 2007). However, broad trends will be overshadowed by local differences, as the impacts of climate change are likely to be highly spatially variable. Climate change will alter the regional distribution of hungry people, with particularly large negative effects in sub-Saharan Africa. Smallholder and subsistence farmers, pastoralists and artisanal fisherfolk will suffer complex, localised impacts of climate change, due both to constrained adaptive capacity in many places and to the additional impacts of other climate-related processes such as snow-pack decrease, particularly in the Indo-Gangetic Plain, and sea-level rise (IPCC, 2007). Furthermore, changes in the frequency and severity of extreme climate events will have significant consequences for food production and food security; it is not only projected mean climate change that will have an impact. Increasing frequencies of heat stress, drought and flooding events are estimated to be likely, even though they cannot be modelled in any satisfactory way with current levels of understanding of climate systems, but these will have adverse effects on crop and livestock productivity over and above the impacts due to changes in mean variables alone (IPCC, 2007).

Of the planet's 1.3 billion poor people, at least 90% of them are located in Asia and sub-Saharan Africa, and climate change will have major impacts on the more than 600 million people who depend on livestock for their livelihoods (Thornton et al., 2002). These impacts will include changes in the productivity of rain-fed crops and forage, reduced water availability and more widespread water shortages, and changing severity and distribution of important human, livestock and crop diseases. Major changes can thus be anticipated in livestock systems, related to livestock species mixes, crops grown, and feed resources and feeding strategies, for example.

The challenges for development are already considerable, and there is now general concern that climate change and increasing climate variability will compound these. However, there is only

limited knowledge about the interactions of climate with other drivers of change in agricultural systems and on broader development trends. Such work is increasingly important for evaluating how farming systems may evolve in the future. Part of this work involves trying to understand the likely impacts of climate change on vulnerable people through its effects in and on other sectors. These include impacts on water resources and other ecosystems goods and services, and human health and nutrition, for example. Enhanced understanding is needed of the likely impacts of climate change on the vulnerability of the resource-poor, so that resilience to current climate variability as well as to the risks associated with longer-term climate change can be gauged, and appropriate actions set in place to increase or restore resilience where this is threatened. (The long term here refers to the next three to five decades, while the short term refers to 3–5 years into the future.)

In this paper, we briefly review some elements of the complex relationship between livestock and climate change in developing countries. Livestock globally play a considerable role in climate change, in terms of their contribution to greenhouse-gas emissions. This has been reviewed and extensively discussed by Steinfeld et al. (2006), and is not dealt with here. Section 2 provides a brief overview of a classification of livestock systems in developing countries, which is used as a framework for the review. Section 3 reviews the literature on what is known concerning the impacts of climate change on livestock. Many of the relationships are two-way (for example, livestock have obvious impacts on water resources and biodiversity, as well as these things being affected by climate change and having impacts on livestock), but that is not the focus here. Some of the livestock-related responses to climate change are considered in Section 4, in terms of possible researchable issues related to adapting to climate change and to mitigating the livestock-related impacts on climate change. Some final remarks are made in Section 5.

## 2. A classification of livestock systems in the developing world

We use the systems classification of Seré and Steinfeld (1996), whose methods were built on the concept of the agro-ecological zone. There are two parts to the classification. The agro-climatic part is based on the length of growing period (LGP), defined as the period in days during the year when the rainfed available soil moisture supply is greater than half the potential evapotranspiration (PET). It includes the period required to evapotranspire up to 100 mm of available moisture stored in the soil profile. Excluded are any time intervals with daily mean temperatures of less than 5 °C. Three categories are defined:

- Arid/semi-arid, with a LGP of less than or equal to 180 days;
- Humid/subhumid, with a LGP greater than 180 days;
- Tropical highlands/temperate. Temperate regions are defined as those with one month or more with monthly mean temperature, corrected to sea level, below 5 °C. Tropical highlands are defined as those areas with a daily mean temperature, during the growing period, of between 5 and 20 °C.

The second part of the classification distinguishes between solely livestock systems and mixed farming systems. Solely livestock systems are those in which more than 90% of dry matter fed to animals comes from rangelands, pastures, annual forages and purchased feeds and less than 10% of the total value of production comes from non-livestock farming activities. Mixed farming systems are livestock systems in which more than 10% of the dry matter fed to animals comes from crop by-products, stubble or more than 10 percent of the total value of production comes from non-livestock farming activities.

**Table 1**

Livestock systems according to the classification of Seré and Steinfeld (1996).

Generic	Specific	System
LG (livestock only)	LGA	Livestock only systems, arid–semiarid (LGP < 180 days)
	LGH	Livestock only systems, humid–subhumid (LGP ≥ 180 days)
	LGT	Livestock only systems, highland/temperate <sup>a</sup>
MR (mixed rainfed)	MRA	Mixed rainfed crop/livestock systems, arid–semiarid (LGP < 180 days)
	MRH	Mixed rainfed crop/livestock systems, humid–subhumid (LGP ≥ 180 days)
	MRT	Mixed rainfed crop/livestock systems, highland/temperate <sup>a</sup>
MI (mixed irrigated)	MIA	Mixed irrigated crop/livestock systems, arid–semiarid (LGP < 180 days)
	MIH	Mixed irrigated crop/livestock systems, humid–subhumid (LGP ≥ 180 days)
	MIT	Mixed irrigated crop/livestock systems, highland/temperate <sup>a</sup>
LL (landless)	LLM	Landless monogastric systems
	LLR	Landless ruminant systems

<sup>a</sup> Temperate regions: areas with one or more months with monthly mean temperature, corrected to sea level, of less than 5 °C. Tropical highlands: areas with a daily mean temperature, during the growing period, of 5–20 °C.

The solely livestock systems are split into two:

- Grassland-based systems, in which more than 10% of the dry matter fed to animals is farm produced and in which annual average stocking rates are less than 10 temperate livestock units per hectare of agricultural land.
- Landless livestock production systems, in which less than 10% of the dry matter fed to animals is produced on the farm and in which annual average stocking rates are above 10 temperate livestock units per hectare of agricultural land. The landless systems are further split into two categories: landless monogastric systems, in which the value of production of the pig/poultry enterprises is higher than that of the ruminant enterprises; and landless ruminant systems, in which the value of production of the ruminant enterprises is higher than that of the pig/poultry enterprises.

The mixed systems are further broken down into the following:

- Rainfed mixed farming systems, in which more than 90% of the value of non-livestock farm production comes from rainfed land use;
- Irrigated mixed farming systems, in which more than 10% of the value of non-livestock farm production comes from irrigated land use.

The classification system of Seré and Steinfeld (1996) thus has eleven system types: livestock only, rangeland-based (LG), which may be arid/semiarid (LGA), humid/subhumid (LGH), or tropical highland/temperate (LGT); landless monogastric-based (LLM), and landless ruminant-based (LLR); mixed, rainfed systems (MR) by the three agro-ecological zones, and mixed, irrigated systems (MI), also by the three agro-ecological zones. The systems are tabulated in Table 1. The system was mapped by Kruska et al. (2003), and detailed methods and examples of each system are shown there.

Clearly, these systems may be affected by climate change in different ways. Impacts on the arid/semiarid rangelands (LGA) of Latin America or sub-Saharan Africa, for example, could be expected to be associated more with effects on pasture (as the major feed in these systems) and water availability, compared with impacts on the tropical-highland mixed, rainfed systems (MRT) of sub-Saharan Africa or South Asia, where the primary effects may be more on crop residues (as a key feeding resource), for example. The following section presents an overview of the impacts of climate change on livestock in relation to these different systems.

### 3. Climate change's impacts on livestock

Impacts of climate change on livestock are outlined below, organised under seven headings: feeds, quantity and quality; heat

stress; water; livestock diseases and disease vectors; biodiversity; systems and livelihoods; and indirect impacts.

#### 3.1. Quantity and quality of feeds

Climate change can be expected to have several impacts on feed crops and grazing systems, including the following (Hopkins and Del Prado, 2007):

- Changes in herbage growth brought about by changes in atmospheric CO<sub>2</sub> concentrations and temperature;
- Changes in the composition of pastures, such as changes in the ratio of grasses to legumes;
- Changes in herbage quality, with changing concentrations of water-soluble carbohydrates and N at given dry matter (DM) yields;
- Greater incidences of drought, which may offset any DM yield increases;
- Greater intensity of rainfall, which may increase N leaching in certain systems.

The impacts of increased atmospheric CO<sub>2</sub> concentration on plant growth are well-studied. It causes partial closure of stomata, which reduces water loss by transpiration and thus improves water-use efficiency (Rötter and van de Geijn, 1999). All other things being equal, this leads to improved crop yield, even in conditions of mild water stress. The effect is much larger for C<sub>3</sub> plants, but there is also a small effect for C<sub>4</sub> plants. Effects on yield, biomass and photosynthesis have been demonstrated in many studies using growth chambers, and a recent review by Long et al. (2006) indicates that yield increases for several C<sub>3</sub> crops may be of the order of 20–30% at elevated CO<sub>2</sub> concentrations of 550 ppm. Large-scale trials under fully open-air field conditions are now possible using free-air concentration enrichment (FACE) technology, and Long et al. (2006) suggested that results from such studies, carried out under more realistic conditions, indicate that the CO<sub>2</sub> fertilisation effect may be only half that estimated from enclosure studies. If so, this would cast doubts on projections that indicate that rising CO<sub>2</sub> concentrations will offset the losses caused by temperature and rainfall effects on the yields of C<sub>3</sub> crops. Tubiello et al. (2007) vigorously defend the data from enclosure experiments (and the crop model developments that were built on their foundation). They also suggest that lower crop responses to elevated CO<sub>2</sub> of the magnitudes in question would not significantly alter projections of global food supply (Tubiello et al., 2007), although the effects at more local scales may be more important in the context of food security. The AR4 gives figures of 10–25% yield increases under unstressed conditions for C<sub>3</sub> crops, and 0–10% increases for C<sub>4</sub> crops, at 550 ppm atmospheric CO<sub>2</sub> concentrations.

Many studies show that temperature and rainfall changes in the future will modify, and often limit, the direct CO<sub>2</sub> effects on plants (IPCC, 2007). The major physiological effects of higher temperatures on plant growth are not easy to isolate, but generally are associated with higher radiation levels and increased water use (Rötter and van de Geijn, 1999). The impacts are clearly site-dependent, too. At higher latitudes, rising temperatures may prolong the growing season, although that effect may be partially offset by lower light levels and trafficability problems of soils in early spring or late autumn (Rötter and van de Geijn, 1999). Higher temperatures in lower latitudes may result in more water stress for plants, although higher temperatures in tropical highland areas may increase their suitability for cropping. All crops have critical high and low temperature thresholds, and these, together with the optimal ranges, differ among crops, among cultivars, and between developmental stages. For the major food crops, these limits and thresholds are well-known and are encapsulated in a variety of process-based crop models such as APSIM (Keating et al., 2003), DSSAT (Jones et al., 2003), EPIC (Williams et al., 1989), and SUCROS and WOFOST (Bouman et al., 1996), for instance. This makes the studying of climate change impacts on food crop growth relatively straightforward (insofar as rainfall, temperature, and CO<sub>2</sub> effects on crop physiology, growth and development are concerned). Much of the large literature on possible impacts using different downscaling techniques and emission scenarios is summarised in AR4. There is much less literature on possible impacts of climate change on either the quantity or the quality of crop residues, key feeding resources in the mixed rainfed (MR) and mixed irrigated (MI) systems.

In terms of impacts on grasslands (the LG systems), sustained increase in mean temperatures results in significant changes in rangeland species distribution, composition, patterns and biome distribution (Hanson et al., 1993), although they also found in a modelling study that doubling CO<sub>2</sub> concentration alone did not significantly increase plant production. Dixon et al. (2003) summarised vulnerability analyses conducted in eight African countries, and concluded that average biomass generally increased for warm-season grasses and decreased for cool-season forbs and legumes as optimal grassland conditions shifted from lower to higher latitudes (although other studies indicate that higher temperatures will often favour forbs and legumes over grasses). But they also noted that there are likely to be smaller impacts on livestock yields per se, compared with grassland biomass, because of the ability of livestock to adjust consumption in response – although whether the area for livestock production can increase, is a very site-dependent question.

Species composition in rangelands and some managed grasslands is an important determinant of livestock productivity. As temperature and CO<sub>2</sub> levels change due to climate change, the optimal growth ranges for different species also change, species alter their competition dynamics, and the composition of mixed grasslands changes. In the temperate regions and subtropics, where grasslands often contain C<sub>3</sub> and C<sub>4</sub> species, some species are more prominent than others in the summer, while the balance of the mix reverts in winter. Small changes in temperature can alter this balance significantly and often result in changes in livestock productivity. The AR4 indicates that in pastures, elevated CO<sub>2</sub> together with increases in temperature, precipitation and N deposition results in increased primary productivity, with changes in species distribution and litter composition. While future CO<sub>2</sub> levels may favour C<sub>3</sub> plants over C<sub>4</sub> plants, the opposite is expected under associated temperature increases. The net effects are uncertain (IPCC, 2007). The key point seems to be that climate impacts on plants depend significantly on the precipitation scenario considered. Changes in evaporation–precipitation ratios modify ecosystem function, particularly in marginal areas, in ways that are

not fully understood (IPCC, 2007). The proportion of browse in rangelands may increase in the future as a result of increased growth and competition of browse species due to increased CO<sub>2</sub> levels (Morgan et al., 2007). This will have significant impacts on the types of animal species that could graze these rangelands and may alter the dietary patterns of the communities dependent from them. In sown mixed pastures, elevated CO<sub>2</sub> increases legume development, and this also occurs in temperate semi-natural grasslands. As AR4 notes, how such results are to be extrapolated is far from clear – it cites a recent study that looked at 1350 European species in terms of their distribution envelopes, and projected that half of these species will become classified as vulnerable or endangered by 2080 because of rising temperatures and precipitation shifts (IPCC, 2007).

Some information exists on the likely impacts of climate change on forage quality, although little seems to be relevant to the tropics. Increased temperatures increase lignification of plant tissues and therefore reduce the digestibility and the rates of degradation of plant species (Minson, 1990). This leads to reduced nutrient availability for animals and ultimately to a reduction in livestock production, which may have impacts on food security and incomes through reductions in the production of milk and meat for small-holders. These impacts may be as important in the rangeland systems (LG) in relation to grazing resources as in the mixed (MR and MI) systems in which crop residues are a key dry-season feeding resource. The modelling study of Hanson et al. (1993) indicates that mean forage digestibility decreased under all scenarios considered. The models simulated an increase in standing biomass but a considerable reduction in the N concentration of plants during the summer grazing months, large enough to bring about considerable decreases in animal performance. Other studies have shown that an increase in the legume content of swards may partially compensate for the decline in protein content of the non-fixing plant species under conditions of elevated CO<sub>2</sub> concentrations. At the same time, the decline of C<sub>4</sub> grasses (which are less nutritious than C<sub>3</sub> plants) may compensate for the reduced protein content under elevated CO<sub>2</sub>. However, the opposite effect is expected under associated temperature increases (IPCC, 2007).

There is general agreement on two things concerning grazing systems and climate change: grassland and (particularly) animal response are very complex; and changing variances in the system may be as important as changing means, if not more so. There is in general a strong relationship between drought and animal death. Projected increased temperature and reduced precipitation in such regions as southern Africa will lead to increased loss of domestic herbivores during extreme events in drought-prone areas. The AR4 summarises the impacts on grasslands for different temperature changes. Warming of 2 °C suggests positive impacts on pasture and livestock productivity in humid temperate regions. By contrast, negative impacts are predicted in arid and semiarid regions (IPCC, 2007).

Very few impact studies have been done for tropical grasslands and rangelands (the LGA, LGH and LGT systems). Some recent work is highlighting the need for a considerable expansion of effort in this area. Tews et al. (2006) describe modelling work to investigate shrub cover dynamics in southern Africa in relation to land-use and climate change, and conclude that much more work is needed using coupled, spatial simulation models of plant population and ecosystem dynamics. In a review of modelling of semiarid grazing systems (LGA) and climate change, Tietjen and Jeltsch (2007) highlight two shortcomings of existing models: being able to model the impacts of increased CO<sub>2</sub> levels on plant productivity and the ability to resolve changes in intra-annual precipitation patterns. These they see as being critical to the making of sustainable long-term decision-making concerning the management of semiarid grazing systems. They call for a new generation of dynamic grazing models



that can provide land managers with the information needed to adapt to climate change.

### 3.2. Heat stress

There does not seem to have been a great deal of work done on the direct impacts of climate change on heat stress in animals, particularly in the tropics and subtropics. [Easterling and Apps \(2005\)](#) state that a lack of appropriate physiological models that relate climate to animal physiology rather limits the confidence that can be placed in predictions of impacts – these authors refers to “a major methodological void”. It is clear, however, that warming will alter heat exchange between animal and environment, and feed intake ([SCA, 1990](#)), mortality, growth, reproduction, maintenance, and production are all affected, potentially.

A literature review by [Sirohi and Michaelowa \(2007\)](#) cites [Hahn \(1999\)](#) in giving the thermal comfort zone for temperate-region adult cattle as being in the range 5–15 °C. [McDowell \(1972\)](#) note that significant changes in feed intake and numerous physiological processes do not occur in the range 5–25 °C. However, the thermal comfort zone is influenced by a range of factors, and is much higher in tropical breeds because of both better adaptation to heat and the lower food intake of most domestic cattle in smallholder systems. Clearly, hot and humid conditions can cause heat stress in livestock, which will induce behavioural and metabolic changes, including reduced feed intake and thus a decline in productivity. There have been several occasions in the last twelve years when heat waves have caused substantial mortality in livestock in the USA and northern Europe ([Sirohi and Michaelowa, 2007](#)).

The vulnerability of livestock to heat stress varies according to species, genetic potential, life stage and nutritional status. Increasing temperatures at higher latitudes are generally going to have greater impacts on livestock than at lower latitudes, where local livestock breeds are often already quite well-adapted to heat stress and drought. Increasing intensification of dairy systems in the developing world through the use of temperate-breed genetic stock could lead to greater vulnerability to increasing temperatures, however. Livestock production in the USA is known to be adversely affected by hot summer weather ([Hahn et al., 1992](#)), and reductions in dairy cow performance associated with climate change in the USA have been projected by [Klinedinst et al. \(1993\)](#).

AR4 also summarises recent literature on heat stress. It confirms the relationship among heat stress, declines in physical activity, and associated (direct and indirect) declines in levels of feed intake ([Mader and Davis, 2004](#)). In addition, high temperatures as well as reduced feed intake put a ceiling on dairy milk yield irrespective of feed intake, and in the tropics, this may be between half and one-third of the potential of modern cow breeds ([Parsons et al., 2001](#)). Increased energy deficits may decrease cow fertility, fitness and longevity ([King et al., 2006](#)). Some modelling work reported by [Chase \(2006\)](#) using the Cornell Net Carbohydrate and Protein System (CNCPS) model indicated that the maintenance energy requirement of a dairy cow weighing 635 kg and yielding 36 kg of milk per day is increased by 22% at 32 °C compared with the energy requirement at 16 °C; for the same temperature increase, predicted dry matter intake decreases by 18% and milk yield decreases by 32%.

[Amundson et al. \(2005\)](#) reported declines in conception rates of *Bos taurus* cattle for temperatures above 23.4 °C and at high values of the thermal heat index. The percentage decreases in confined pig, beef and dairy milk production to 2050 for the USA associated with increasing heat stress are in the range 1–2% ([Frank et al., 2001](#)).

[Rötter and van de Geijn \(1999\)](#) suggest that impacts of heat stress may be relatively minor for the more intensive livestock production systems where some control can be exercised over the

exposure of animals to climate (particularly the LLM and LLR systems). The wide geographic distribution of livestock production is some evidence for its adaptability to different climates. As these authors point out, livestock are a much better hedge than crops against extreme weather events such as heat and drought. Even so, whether the mean temperature increases of the coming decades are within the range that can be tolerated or not by existing distributions of different genotypes of cattle in the tropics, is essentially unknown. Similarly, the impacts of increased frequencies of extreme heat stress on existing livestock breeds are not known, nor do we know if there are critical thresholds in the relationship between heat stress and physiological impacts. Nevertheless, the tropics and subtropics contain a wealth of animal genetic resources that could be utilised in relation to heat-stress-related issues. There is considerable value in better understanding the match between livestock populations, breeds and genes with the physical, biological and economic landscape; this landscape livestock genomics approach should lead in the future to understanding the genetic basis of adaptation of the genotype to the environment ([Seré et al., 2008](#)). Over this longer term, ongoing genetic improvement through both natural and artificial selection should allow a certain degree of adaptation to gradual changes in climate to occur.

### 3.3. Water

Globally, freshwater resources are relatively scarce, amounting to only 2.5% of all water resources, and of this, not quite 70% is locked up in glaciers and permanent ice ([MA, 2005](#)). Estimates of the renewable global water supply are very imprecise, but lie between 33,500 and 47,000 cubic km per year, about one-third of which is accessible to humans, once its physical proximity to human population and year-to-year variability are taken into account ([Postel et al., 1996](#)). Groundwater also plays an important role in water supply – between 1.5 and 3 billion people depend on groundwater for drinking ([MA, 2005](#)). There is considerable uncertainty associated with estimating available groundwater resources and their recharge rates, and this makes assessments of water use particularly challenging.

The agricultural sector is the largest user of fresh water resources, accounting for some 70% of water use. Irrigated areas have increased fivefold over the last century. Even so, the growth in water use by other sectors has been faster in recent decades than for agriculture (cited in [Steinfeld et al., 2006](#)). Global freshwater use is projected to expand 10% from 2000 to 2010, down from a per decade rate of 20% between 1960 and 2000, reflecting population growth, economic development, and changes in water-use efficiency ([MA, 2005](#)). Globally, each person consumes 30–300 l of water per day for domestic purposes, while it takes 3000 l per day to grow each person's food ([Turner et al., 2004](#)).

Perhaps the key issue relating to water is its uneven distribution. The [MA \(2005\)](#) states that water scarcity is a globally significant and accelerating condition for 1–2 billion people worldwide, resulting in problems with food production, human health, and economic development. By 2025, 64% of the world's population will live in water-stressed basins, compared with 38% today ([Rosegrant et al., 2002](#)).

The extent and nature of livestock's role in the global water use equation is the subject of considerable debate. Water use in the livestock sector includes not only the water used at farm level for drinking and the growing of feed crops, but also other servicing and product processing roles. [Steinfeld et al. \(2006\)](#) provide quantitative estimates of direct and indirect water use in the livestock sector, and discuss livestock's role in water pollution. They cite very large differences in service water requirements for different livestock systems, from 0 l/animal/day in extensive grazing

systems (LGA) to 125 l/animal/day in industrial, landless pig production systems (LLM), for example.

There are, however, considerable difficulties involved in assessing water use in the livestock sector. Part of the problem relates to the challenges in defining terms and appropriate “system boundaries”: Peden et al. (2007) cite figures for water use in grainfed beef production that range from 15,000 to 100,000 l/kg – this is clearly a very inexact science. Another part of the problem, however, lies in the fact that not all agricultural production is equal; crop- and livestock-derived protein are not equal when it comes to their value in human nutrition, particularly in children's diets. A third part of the problem is that the contribution of livestock to rural livelihoods for very many people in developing countries goes far beyond what can be easily monetarised – and hence it is usually ignored. Obviously, the situation is very different in developed countries.

The impacts of climate change on fresh water supply have received considerable attention. The AR4 states with high confidence that the negative impacts of climate change on freshwater systems outweigh its benefits in all regions. Areas in which runoff is projected to decline are likely to face a reduction in the value of the services provided by water resources. The beneficial impacts of increased annual runoff in other areas will be tempered by the negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality, and flood risks. Using the SRES A1B emissions scenario (Nakicenovic et al., 2000) and an ensemble of 12 different General Circulation Models (GCMs), there is good agreement in the sign of runoff change for large areas of the globe: increases of between 10% and 40% in the high latitudes of Eurasia and North America, and some agreement of increases in the wet tropics. Prominent regions with decreasing runoff of between 10% and 30% include the Mediterranean and southern Africa.

Climate change will also affect groundwater recharge rates, but there is much less certainty as regards to how. Even current knowledge of recharge rates and levels in both developed and developing countries is poor. What studies there are indicate that, while globally runoff rates may increase by 9% to the 2050s under the SRES A2 emissions scenario (using the ECHam4 GCM), groundwater recharge rates may increase by only 2%. Groundwater recharge rates are projected to decrease dramatically in certain areas such as north-eastern Brazil, south-west Africa, and along the southern rim of the Mediterranean, but there is considerable uncertainty in such results.

The impacts of such supply changes on livestock and livestock systems in developing countries have not been well-studied. A case-study in a region of Botswana concludes that the key contribution of groundwater to extensive grazing systems (LGA systems) will become even more important in the future in the face of climate change, although the impacts on recharge rates of the aquifers involved are essentially unknown (Masike, 2007). The increased reliance on groundwater in the future in Botswana for both the cattle sector and for urban water supply could lead to problems associated with the sustainability of water resources in the country. Considerably more information is needed in such cases, so that more complete quantification of the extent of the problem can be carried out. Such information could then lead to appropriate policies being implemented that can address the sustainability and water allocation issues, which in the future may be considerable (Masike, 2007).

There is rather less uncertainty in relation to the likely impacts of climate change on water demand by livestock. The response of increased temperatures on water demand by livestock is well-studied. For *Bos indicus*, for example, water intake increases from about 3 kg/kg DM intake at 10 °C ambient temperature, to 5 kg at 30 °C, and to about 10 kg at 35 °C (NRC, 1981). For *Bos taurus*, intake at the same three temperatures is about 3, 8 and 14 kg/kg DM intake. Some of this water intake comes from forage, and

forage water content itself will depend on climate-related factors in well-understood ways: forage water content may vary from close to 0–80%, depending on species and weather conditions. Howden and Turnpenny (1998) present a simple water demand model for cattle, and estimate that under Australian conditions, water requirements for beef cattle are likely to increase by around 13% for the climate scenarios simulated. They also simulated a substantial increase in the number of stress days per year when animals could no longer thermoregulate by sweating alone. These authors conclude that further selection for cattle lines with effective thermoregulatory control will be needed in future, although it may be difficult to combine the twin desirable traits of adaptation to high-temperature environments with high production potential.

In summary, while the response of livestock to known increases in temperature is predictable, in terms of increased demand for water, attempts to quantify the impacts of climate change on water resources in the land-based livestock systems in developing countries are fraught with uncertainty, particularly in situations where groundwater accounts for a substantial portion of the supply of water to livestock, which is the case in many grazing systems, for example. The coming decades will see increasing demand and competition for water in many places, and policies that can address allocation and efficiency issues will increasingly be needed.

#### 3.4. Livestock diseases and disease vectors

The impacts of changes in ecosystems on infectious diseases depend on the ecosystems affected, the type of land-use change, disease specific transmission dynamics, and the susceptibility of the populations at risk (Patz et al., 2005a) – the changes wrought by climate change on infectious disease burdens may be extremely complex. Climate change will affect not only those diseases that have a high sensitivity to ecological change, but there are also significant health risks associated with flooding. The major direct and indirect health burdens caused by floods are widely acknowledged, but they are poorly characterised and often omitted from formal analyses of flood impacts (Few et al., 2004).

There is quite a large literature on the prospective impacts of climate change on health and disease, but much of it is devoted to human health and vector-borne disease, unsurprisingly. The effects of climate change on livestock and non-vector-borne disease have received only limited attention, however (e.g., Cook, 1992; Harvell et al., 1999, 2002). As Baylis and Githeko (2006) note, given the global burden of disease that is not vector-borne, and the contribution of animal diseases to poverty in the developing world, this needs to be rectified. In their review (on which this section is based), Baylis and Githeko (2006) discuss several ways in which climate change may affect infectious diseases:

*Effects on pathogens:* higher temperatures may increase the rate of development of pathogens or parasites that spend some of their life cycle outside their animal host, which may lead to larger populations (Harvell et al., 2002). Other pathogens are sensitive to high temperatures and their survival may decrease with climate warming. Similarly, those pathogens and parasites that are sensitive to moist or dry conditions may be affected by changes to precipitation, soil moisture and the frequency of floods. Changes to winds could affect the spread of certain pathogens and vectors.

*Effects on hosts:* Baylis and Githeko (2006) mention that mammalian cellular immunity can be suppressed following heightened exposure to ultraviolet B radiation, which is an expected outcome of stratospheric ozone depletion. So greenhouse-gas emissions that affect ozone could have an impact on certain animal diseases, although this link has not been studied in livestock. A more important effect may be on genetic resistance to disease. While animals often have evolved genetic resistance to diseases to which they are

commonly exposed, they may be highly susceptible to “new” diseases. Climate change may bring about substantial shifts in disease distribution, and outbreaks of severe disease could occur in previously unexposed animal populations (possibly with the breakdown of endemic stability).

**Effects on vectors:** there may be several impacts of climate change on the vectors of disease (midges, flies, ticks, mosquitoes and tsetse are all important vectors of livestock disease in the tropics). Changes in rainfall and temperature regimes may affect both the distribution and the abundance of disease vectors, as can changes in the frequency of extreme events (outbreaks of some mosquito-borne diseases have been linked to El Niño–Southern Oscillation (ENSO), for example). It has also been shown that the ability of some insect vectors to become or remain infected with viruses (such as bluetongue) varies with temperature (Wittmann and Baylis, 2000). The feeding frequency of arthropod vectors may also increase with rises in temperature. As many vectors must feed twice on suitable hosts before transmission is possible (to acquire and then to transmit the infection), warmer temperatures may increase the likelihood of successful disease transmission.

**Effects on epidemiology:** climate change may alter transmission rates between hosts not only by affecting the survival of the pathogen or parasite or intermediate vector but also by other means. Future patterns of international trade, local animal transportation, and farm size are factors that may be driven in part by climate change, and may affect disease transmission.

**Other indirect effects:** climate change may also affect the abundance and/or distribution of the competitors, predators and parasites of vectors themselves, thus influencing patterns of disease. It may also be that changes in ecosystems, driven by climate change and other drivers that affect land-use, could give rise to new mixtures of species, thereby exposing hosts to novel pathogens and vectors and causing the emergence of new diseases (WHO, 1996).

The impacts of climate change on livestock disease may be very complex, and studying them needs to go well beyond any simple assessment of rainfall and temperature effects on distribution, although that is a start. Examples of this type of analysis have been done for several diseases of livestock in developing countries. Rogers (1996) looked at possible climate change impacts on the distribution of the brown-ear tick, *Rhipicephalus appendiculatus*, the primary vector of East Coast Fever, a disease that affects both grazing (LG) and mixed (MR) systems in eastern and southern Africa. By the 2050s, suitable habitat is projected to have largely disappeared from the south-eastern part of its existing range (south-eastern Zimbabwe and southern Mozambique), although its range may expand in western and central parts of southern Africa. In another study that looked at possible impacts of climate change on a major disease of livestock in African livestock systems, cattle trypanosomiasis, Thornton et al. (2006a) investigated climate-driven changes in habitat suitability for the tsetse fly vector. While climate will modify habitat suitability for the tsetse fly, the demographic impacts on trypanosomiasis risk through bush clearance are likely to outweigh those brought about by climate change. A similar result was found in a modelling study of changes in malaria distribution in Africa by Hay et al. (2006). Climate change may increase the numbers of people at risk from this disease, but that these increases are small when compared with the likely impacts of demographic changes. Randolph (2008) cautions that there are no a priori reasons for expecting that climate change will necessarily lead to increases in disease risk in general, and in general a multitude of interacting factors determine infection risk and exposure of livestock and humans to that risk.

More integrated assessments have been attempted, that go beyond the distributional effects of the vector of disease, although to date these have tended to have a developed-country focus. White

et al. (2003) simulated the increased vulnerability of the Australian beef industry to the cattle tick (*Boophilus microplus*). They calculated economic losses in relation to tick populations and productivity reductions, and assessed switching breeds as an adaptation option. Their results are perhaps more interesting in relation to the uncertainties and assumptions made, and their key conclusion that risk assessments of climate change should extend to all relevant variables, where this is possible.

AR4 does not have much to say on plant and animal diseases. It notes that new studies are focusing on the spread of animal diseases and pests from low to mid-latitudes due to warming. Models project that bluetongue, which mostly affects sheep and occasionally goat and deer, will spread from the tropics to mid-latitudes (Anon, 2006). Most assessments do not explicitly consider the impacts on livestock health as a function of CO<sub>2</sub> and climate combined. Whether CO<sub>2</sub> impacts are important or not in this regard, is essentially unknown.

Perhaps more than other livestock-related impacts, climate change effects on livestock disease suffer intrinsic problems of predictability. This is due in part to the nature of disease. As Baylis and Githeko (2006) note, climate change-driven alterations to livestock husbandry in Africa, if they occur, could have many indirect and unpredictable impacts on infectious animal disease in the continent. It has been observed that combinations of drought followed by high rainfall have led to wide-spread outbreaks of diseases such as Rift Valley Fever and bluetongue in East Africa and of African horse sickness in the Republic of South Africa (Baylis and Githeko, 2006). The predictability of events such as ENSO in current GCMs is poor, so while it is likely that outbreaks of certain vector-borne diseases will become more common in parts of Africa, we are very limited when it comes to predicting when and where these are likely to occur. In addition to this, Kovats et al. (2001) note that there has been a tendency to oversimplify the mechanisms by which climate change may affect disease transmission. There are in general many factors operating, and considerably more work is needed on disease dynamics and how these may adapt to a changing climate. These things make impact assessment of livestock diseases in developing countries particularly challenging.

### 3.5. Biodiversity

Modern drivers of change are already having substantial impacts on biodiversity. The loss of genetic and cultural diversity in agriculture as a result of the forces of globalisation, for example, are summarised by Ehrenfeld (2005). He notes the case of rice varieties in India – in 20 years' time, rice diversity will be reduced to 50 varieties, the top 10 of these accounting for more than 75% of the country's rice area – to be contrasted with the fact that probably something like 30,000 different indigenous varieties have been grown in India over the last 50 years. Similar scales of loss have been seen in varieties of domestic animals; of the nearly 4000 breeds of ass, water buffalo, cattle, goat, horse, pig and sheep recorded in the 20th century, some 16% had become extinct by 2000, and 12% of what was left was rare. The 2007 FAO report on animal genetic resources indicates that 20% of reported breeds are now classified as at risk, and that almost one breed per month is becoming extinct (CGRFA, 2007). There is considerable regional variation, however. In developed regions, 20–28% of mammalian species are classified as at risk, and these regions have highly specialized livestock industries, in which production is dominated by a small number of breeds. For developing regions, the proportion of mammalian species at risk is lower (7–10%), but 60–70% of mammals are classified as being of unknown risk status (CGRFA, 2007).

Much of this genetic erosion is attributed to global livestock production practices and the increasing marginalisation of traditional production systems and associated local breeds. The drivers



of these changes in developing countries depend on the system (Seré et al., 2008). In the landless industrial systems (LLM, LLR), genetic resources are essentially the preserve of the private sector. In the mixed systems in developing countries (MR, MI), the pressures to intensify to meet demand are increasingly involving crossbreeds with exotic breeds, while in the grazing systems (LG), high levels of diversity are often encountered and traits of disease-resistance and tolerance of harsh environments are widely present. However, livestock numbers are frequently declining in these systems, and small endemic populations are particularly at risk (Seré et al., 2008).

The potential for widespread genetic devastation in the future as a result of inexorably rising temperatures is great. A 2.5 °C increase in global temperature above the pre-industrial level may see major biodiversity losses: 41–51% loss of endemic plants in southern Africa, anything between 13% and 80% of various fauna in the same region (IPCC, 2007). AR4 estimates that 20–30% of all plant and animal species assessed so far would be at high risk of extinction with such a temperature rise. That is equivalent to the A2 SRES scenario running out to about 2060. With a 4.5 °C increase, we would see major extinctions globally, and few ecosystems would be able to adapt: this is a temperature change equivalent to the A2 emission scenario run out to about 2120 (IPCC, 2007).

The impacts of such losses are difficult to imagine, and the problems that will be caused by the loss of genes for disease and pest resistance, for environmental adaptation, and for other desirable traits in both plants and animals, cannot be over-stressed. Ecosystems and species are very likely to show a wide range of vulnerabilities to climate change, depending on the imminence of exposure to ecosystem-specific, critical thresholds. Corals reefs and boreal forests are examples of highly vulnerable systems, where changes brought about by climate change are already observable (IPCC, 2002). Less-vulnerable ecosystems include savannas and species-poor deserts, although this assessment is fraught with uncertainty related to CO<sub>2</sub> fertilisation effects and the impacts of disturbance regimes such as fire (IPCC, 2007).

There is no doubt that the livestock sector itself is a major driver in habitat and landscape change, and thus plays a significant role in biodiversity loss. These impacts are discussed by Steinfeld et al. (2006), for example. But in general, isolating the likely impacts of different drivers (including climate change) on genetic diversity is extremely difficult. The data and models needed to project the extent and nature of future ecosystem changes and changes in the geographical distribution of species are still incomplete; the implication is that these effects can only be partially quantified (IPCC, 2002). Such models would need to take account of human land- and water-use patterns as well, factors that will greatly affect the ability of plants and animals to respond to climate change. Indeed, as the MA (2005) notes, a considerable amount of new research is needed to understand the role of different components of biodiversity in the provision of ecosystem goods and services. (Ecosystem goods, i.e., items with monetary value, include food, materials used for construction, etc. Ecosystem services, which are rarely traded, include climate regulation, maintenance of hydrological cycles, the cleansing of water and air, etc.). Then in getting from even that point to a realistic and detailed assessment of the impacts of climate change on biodiversity in different ecosystems, there is a mountain to climb. A good start could be made by improving animal genetic resources characterization, use and conservation (Seré et al., 2008).

Animal and plant genetic resources are the ultimate non-renewable resource; once gone, they are gone for good. Their importance is critical, but the complexity of ecosystems means that it is extremely difficult to assess the impacts of climate change on biodiversity. Animal and plant genetic resources have extremely high value, and the costs associated with their loss may be

simply enormous, but to all intents and purposes neither their value nor the costs of their loss can be realistically quantified. Given that this situation is not likely to change very rapidly in the future, it makes much sense for any consideration of climate change and biodiversity to emphasise conservation as well as attempting to fill critical knowledge gaps to enable realistic assessments to be carried out on the likely impacts of adaptation and mitigation activities on biodiversity and other aspects of sustainable development (IPCC, 2002). As CGRFA (2007) notes, pastoralists and smallholders are the guardians of much of the world's livestock genetic resources. This poses particularly challenging problems for conservation, but there is a great deal that can and must be done, in the search for appropriate and effective schemes of biodiversity management, including the setting up and implementation of appropriate institutional and policy frameworks (Seré et al., 2008).

### 3.6. Systems and livelihoods

Most of the work done on agricultural impacts of climate change has focussed on crops, and there is relatively very little literature on the impacts of climate change on farming systems, whether they contain livestock or not. There is a considerable literature from a development perspective on how farming systems may change in response to key drivers. For example, a general model of crop–livestock interactions and intensification first developed by Boserup (1965) and expanded by McIntire et al. (1992) describes system change as an endogenous process in response to increased population pressure. As the ratio of land to population decreases, farmers are induced to adopt technologies that raise returns to land at the expense of a higher input of labour, the direct causal factor being relative factor price changes. This generalised framework may be modified by many factors other than population growth. Environmental characteristics play a significant role in determining the nature and evolution of crop–livestock systems, as do factors such as economic opportunities, cultural preferences, climatic events, lack of capital to purchase animals, and labour bottlenecks at key periods of the year that may prevent farmers from adopting technologies such as draft power (Baltenweck et al., 2003).

Livestock systems in developing countries are extremely dynamic. Various drivers of change can be identified: increasing populations and incomes are combining to drive considerable growth in demand for livestock products, and this is projected to continue well into the future (Delgado et al., 1999), although at diminishing rates (Steinfeld et al., 2006). One implication of this is the intensification of land use in the production of livestock feed. A second feature of the growing demand for livestock products is the shift in location of livestock production: the rapid urbanisation of (particularly monogastric) livestock production (the LLM systems), followed in time by ruralisation again, primarily in response to environmental drivers.

In addition to the factors associated with the “livestock revolution” (Delgado et al., 1999) and “livestock in geographic transition” (Steinfeld et al., 2006), other drivers may have far-reaching impacts on the livestock sector in the coming decades: the green agriculture movement (organic food, fair trade, etc.) and the increasing importance of crops being grown for biofuel, for example. There may be considerable impacts of climate change on agricultural systems in the future, but it is clear that climate change is only one of several key drivers of change; population growth, globalisation, urbanisation, changing socio-economic expectations, and cultural preferences, for example, may have considerable impacts on the system and on food security and poverty.

To date, there have been few genuinely integrative attempts to disentangle the complexity of systems' evolution in developing countries in relation to climate change. There is quite a lot of



literature on the likely biome effects of climate change to the end of the century. The study by [Schaphoff et al. \(2006\)](#) is an example, although the uncertainties involved, here relating to carbon storage of the vegetation that emerges as a result of projections of climate change, are considerable: the GCMs used for the analysis do not always agree even as to whether specific regions will become a source or a sink of carbon. The response of grazing (LG) systems to global change was reviewed by [Asner et al. \(2004\)](#), but these authors conclude that the lack of process-based knowledge limits predictive capabilities – “We are currently unable to forecast the onset of desertification, woody encroachment, or even deforestation because we lack the approaches to understand the interactions among ecological, climatological, and socioeconomic factors”.

Little has been done on assessing impacts at the level of the agricultural system, although [Harle et al. \(2007\)](#) is an exception. They assess likely impacts on the Australian wool sector to 2030, and integrate impacts on pasture growth and quality, animal productivity, wool quality, animal diseases, and stresses on the landscape. While the combination of these impacts is predicted to reduce productivity in the more marginal areas, it may increase production in others. They conclude that the Australian wool production system is relatively robust for the next 25 years anyway, and that early adaptation of options such as low-emission grazing systems, more sustainable management of the rangelands, and improved management of climatic variation, could significantly reduce the downsides of climate change impacts ([Harle et al., 2007](#)).

Some other work has been done in relation to how the geographic boundaries of agricultural systems may shift in response to changing population densities and climate. The movement of the potential cropping boundary (defined in terms of soil suitability and growing periods long enough to allow annual cropping) in Africa in response to climate change projections from one GCM and one SRES scenario was mapped in [Thornton et al. \(2002\)](#), as were likely transitions from rangeland (LG) to mixed (MR) systems in response to increasing population densities to 2050. As might be expected, there is some contraction of the cropping zone at both its northern and southern borders, although there would appear to be some additions to the areas where cropping may be possible in a few parts of East Africa, particularly in the highlands (a relaxation of the cold temperature constraint, mostly). Parts of East and southern Africa are likely to see considerable shifts in cropping and livestock activities ([Jones and Thornton, in press](#); [Thornton et al., 2009](#)). Transitions are already occurring: in marginal areas of southern Africa, the reductions in length of growing period and the increased rainfall variability is driving systems to a conversion from a mixed crop–livestock system to a rangeland-based system, as farmers find growing crops too risky in those marginal environments. These land-use changes can lead to a different composition in animal diets and to a change in the ability of smallholders to manage feed deficits in the dry season. These two effects can have substantial effects on animal productivity and on the maintenance of livestock assets.

The broad-brush vulnerability assessment work of [Thornton et al. \(2006b\)](#) attempted to identify the agricultural systems in Africa most at risk from climate change; these include the rangeland-based arid–semiarid (LGA) and mixed rainfed arid–semiarid (MRA) systems in substantial parts of West, East and southern Africa, for example. More integrative work is needed on seeing how the systems themselves might change in the future, however. In addition to population and climate changes, some type of land-use model is needed for this, coupled with the development of plausible scenarios of the future. Inevitably, this kind of work will have to be based on scenario analysis, as vulnerability changes will be dependent on a whole host of factors in addition to climate change. The scenarios developed for the Millennium Ecosystem Assessment, for example, were designed to explore contrasting

transitions of society as well as contrasting approaches to policies for managing ecosystem services ([MA, 2005](#)), and these have also formed the basis for work designed to investigate the future of the livestock sector in developing countries ([Freeman et al., 2007](#)).

While the development of plausible scenarios of the future is necessarily qualitative, a lot of work has been done on quantifying some aspects of these, using a mixture of different types of models at different scales ranging from the global trade system to the agricultural sector in different regions (an example is [Rosegrant et al. \(2009\)](#), which evaluates the relevance, quality and effectiveness of agricultural knowledge, science, and technology). Despite the gaps in our knowledge of some of the relevant processes, a large assortment exists of modelling tools that could be utilised to assess climate change impacts on systems and households – many of these are reviewed in [Nicholson \(2007\)](#). [Rivington et al. \(2007\)](#) argue that any effective integrated assessment approach will need to combine simulation modelling with deliberative processes involving all stakeholders. The key issue seems to be more to do with generalising the results of case studies of changing land-use patterns and livelihood dynamics, such as that of [Soini \(2005\)](#) concerning the Chagga farming systems on the slopes of Kilimanjaro. There is a critical need to develop generalisable lessons concerning likely future vulnerability to climate (and other) changes, and the adaptation options that may be appropriate.

In sum, tropical farming systems are often highly complex, and usually involve a mixture of crops of widely differing tolerance to drought and temperature increases. If production levels of human food and livestock feed are likely to decrease or even change relative to each other, the resultant dietary energy deficits have to be met from somewhere ([Jones and Thornton, 2003](#)). Such considerations indicate that while single-enterprise impact assessment of climate change effects is a start, the interactions that exist in most tropical farming system are such that assessment has to be done at the level of the system. Without a systems-orientated assessment of household vulnerability, it is hard to see how effective adaptation work can be appropriately targeted. From this perspective, the lack of work done on systems' impacts of climate change is a serious void.

### 3.7. Indirect impacts

In addition to the direct impacts of a changing climate on many aspects of livestock and livestock systems, there are various indirect impacts that can be expected to impinge on livestock keepers in developing countries. One of the most significant of these is the impact on human health. As with livestock diseases, the changes wrought by climate change on infectious disease burdens may be extremely complex. [Patz et al. \(2005a\)](#) list several diseases as high priority for their large global burden of disease and their high sensitivity to ecological change. For the tropics, these include malaria across most systems; schistosomiasis and lymphatic filariasis in cultivated and inland water systems in the tropics; dengue fever in tropical urban centres; leishmaniasis and Chagas disease in forest and dryland systems; meningitis in the Sahel; and cholera in coastal, freshwater and urban systems. Impacts of climate change on malaria distribution, for example, are likely to be largest in Africa and Asia ([Van Lieshout et al., 2004](#)), although climate change is not likely to affect malaria transmission in the least developed countries where the climate is already highly favourable for transmission.

In addition, climate change will have further impacts on heat-related mortality and morbidity and on the incidence of climate-sensitive infectious diseases ([Patz et al., 2005b](#)), and these may be considerable.

While climate change impacts may have few direct impacts on other important diseases such as HIV/AIDS, climate variability

**Table 2**

Some of the knowledge gaps of climate change impacts on livestock-based systems and livelihoods in the tropics and subtropics.

Area	Gap
Feeds: quantity and quality	<ul style="list-style-type: none"> <li>• Rangelands (LG): primary productivity impacts, species distribution and change due to CO<sub>2</sub> and other competitive factors, estimation of carrying capacities</li> <li>• Mixed systems (MR, MI): localised impacts on primary productivity, harvest indexes and stover production</li> </ul>
Heat stress	<ul style="list-style-type: none"> <li>• What is the extent of the problem, in a development context?</li> </ul>
Water	<ul style="list-style-type: none"> <li>• Surface and groundwater supply, and impacts on livestock (particularly LG systems)</li> <li>• Effective ways to increase livestock water productivity</li> </ul>
Diseases and disease vectors	<ul style="list-style-type: none"> <li>• How may the prevalence and intensity of key epizootic livestock diseases change in the future?</li> <li>• How may climate change affect diseases as systems intensify (particularly MR, MI, LL systems)?</li> </ul>
Biodiversity	<ul style="list-style-type: none"> <li>• 'Ecological biodiversity': what will happen to numbers of species as systems change?</li> <li>• Animal breed biodiversity: can the animal genetic resources that might be useful in the future be specified?</li> </ul>
Livestock systems	<ul style="list-style-type: none"> <li>• Localised impacts on livelihoods</li> <li>• How will systems evolve in future?</li> <li>• Magnitude and effects of systems changes on ecosystems goods and services</li> </ul>
Indirect impacts	<ul style="list-style-type: none"> <li>• How do human health impacts of climate change intertwine with livelihood systems and vulnerability?</li> </ul>

impacts on food production and nutrition can affect susceptibility to HIV/AIDS as well as to other diseases (Williams, 2004). HIV/AIDS is a major development issue facing sub-Saharan Africa: the epidemic deepens poverty, reverses human development achievements, worsens gender inequalities, erodes the ability of governments to maintain essential services, reduces labour productivity and supply, and puts a brake on economic growth (Drimie, 2002). The HIV/AIDS issues concerning land use relate to reduced accessibility to labour, less capital to invest in agriculture, and less productive households, as well as issues related to land rights and land administration (Drimie, 2002).

Migration has been a catalyst in the rapid spread of HIV, particularly in southern Africa (Anantram, 2006). There are several links between migration and HIV/AIDS prevalence, including the high vulnerability of migrants who are often marginalised from health and social services. Climate change is certainly likely to be a driving factor of migration in the future, because of displacement due to extreme weather events and sea-level rise, and/or deteriorating agricultural productivity. In short, there is a critical two-way relationship between HIV/AIDS and food security, and impacts on the latter are significant determinants of both direct and indirect impacts of climate change on poor people (Anantram, 2006).

### 3.8. Summary of some key knowledge gaps

Some of the major knowledge gaps concerning climate change impacts on livestock-based systems and livelihoods that may be of particular importance in developing countries are shown in Table 2, drawn from the brief overview sections above. The gaps identified vary widely in their specificity and scope. There are also differences in their likely developmental relevance, although in the absence of more information it is difficult to say much about these. It might reasonably be concluded, for example, that impacts of climate change on livestock-based livelihoods in local settings will probably be more relevant for poverty-alleviation goals than heat stress issues, but beyond this, some priority setting within a formalised, quantitative *ex ante* impact assessment framework is clearly called for.

## 4. Responses to climate change impacts in livestock systems

If the European Union target of stabilising climate temperature increases to 2 °C above pre-industrial levels is to be met, this is likely to require stabilisation of the CO<sub>2</sub> concentration below 450 ppm. This is certainly possible, and some see this as an economically attractive goal (Stern, 2006). Meeting this target will need to involve the implementation of stringent climate policies and very substantial cutting of greenhouse-gas emissions. Given

that there are considerable lags in the earth system, climate change impacts are inevitable in the coming decades, even if all emissions were cut tomorrow. Particularly for vulnerable people, adaptation options will be needed if households are to cope with the changes brought about. Some of these options may be able to reduce the negative impacts of livestock on climate (mitigation) while at the same time increasing household food security, income, and/or system resilience (adaptation). In this section, we highlight some key researchable issues related to adaptation and mitigation associated with livestock systems in the tropics and subtropics.

### 4.1. Adaptation

The AR4 notes that a wide array of adaptation options is available, but more extensive adaptation than is currently occurring is needed to reduce vulnerability to future climate change. There are barriers, limits, and costs, but these are not fully understood, let alone quantified (IPCC, 2007). There is a great variety of possible adaptive responses available, including technological (such as more drought-tolerant crops), behavioural (such as changes in dietary choice), managerial (such as different farm management practices), and policy options (such as planning regulations and infrastructural development). Adaptation options to climate change has been summarised by Kurukulasuriya and Rosenthal (2003), who define a typology of adaptation options that includes the following:

- Micro-level adaptation options, including farm production adjustments such as diversification and intensification of crop and livestock production; changing land use and irrigation; and altering the timing of operations.
- Income-related responses that are potentially effective adaptation measures to climate change, such as crop, livestock and flood insurance schemes, credit schemes, and income diversification opportunities.
- Institutional changes, including pricing policy adjustments such as the removal or putting in place of subsidies, the development of income stabilization options, agricultural policy including agricultural support and insurance programs; improvements in (particularly local) agricultural markets, and the promotion of inter-regional trade in agriculture.
- Technological developments, such as the development and promotion of new crop varieties and livestock feeds, improvements in water and soil management, and improved animal health technology.

There are many factors that will determine whether specific adaptation options are appropriate and viable in particular loca-

tions, including their time horizon. The short- and long-term distinction in relation to adaptation is important, as two separate but related approaches are commonly pursued. Some adaptation to climate change is perhaps best framed within the context of risk management. [Washington et al. \(2006\)](#) outline an approach to addressing the challenges of climate change in Africa that depends on a close engagement with climate variability. They argue that “... addressing climate on one time scale may be the best way to approach the informational and institutional gaps that limit progress at another, longer time scale.” This stems from two key constraints: the lack of (and problems associated with) climate data; and the relative scarcity of climate scientists from Africa. The underlying rationale for a risk management approach is based on the fact that neither farmers nor elected policy makers have much interest in events 30–50 years in the future. A risk management approach is an effective way of bringing the issues associated with climate change to the “here and now”. Helping decision makers understand and deal with current levels of climate variability can clearly provide an entry point to the problems posed by increasing variability in the future and to the options that may be needed to deal with it. Indeed, there are now frequent calls from climate scientists and policy makers for a more practical approach to the use of climate change scenarios, in the search to make them more socially relevant (e.g., [Schiermeier, 2007](#)). While the debate may be shifting from high-level advocacy on “the need to act” – this argument seems to be essentially over – to considerations of regional- and country-level responses on “how to” adapt ([Wilby, 2007](#)), there are still problems relating to the uncertainty of climate projections and projected impacts and how this uncertainty can be appropriately treated in the search for “social relevance” ([Wilby et al., in press](#)).

In any case, the “climate change as a risk management issue” approach is being (or has been) institutionalised in many organisations, including the World Bank ([van Aalst, 2006](#)). There is already a large literature on the uses of climate information for adaptation, and these uses have been categorised by [Smit et al. \(2000\)](#), for example. Several studies demonstrate the utility of climate risk management approaches for adaptation in the water, health and agricultural sectors. In the African context, there are still challenges to be overcome, however, particularly those relating to gaps between development and climate communities and the issues noted above of data and technical capacity ([Hellmuth et al., 2007](#)). The importance of mainstreaming such work as part of development is also highlighted in the synthesis of adaptation studies of the AIACC (Assessments of Impacts and Adaptations to Climate Change) programme ([Leary and Kulkarni, 2007](#)).

Not all adaptation issues are most appropriately seen in a risk management light. Approaches to longer-term adaptation are often couched in terms of “climate-proofing development”. Practically all research-for-development activity has to take climate change into account, as the lag time between problem identification and

the development of appropriate technology is often very long. The first generation of drought-tolerant beans in Latin America is only now reaching the release phase, and that work has taken 30 years so far ([Jones et al., 2008](#)) – this is by no means atypical.

Longer-term research activities need to be viewed from a highly future-orientated perspective, therefore. As noted above, climate change in Kenya may allow production opportunities to be expanded in some places in the highlands, owing to increased rainfall and higher temperatures that may increase suitability for particular crops. By the same token, livestock disease burdens will change because changing conditions will affect the survival and prevalence of pathogens, parasites and intermediate vectors of disease. Further, the natural resource management issues may become more or less acute, depending on the situation, but we can readily speculate that in the some of the pastoral lands of Kenya, increasing temperatures will affect water availability for cattle, with concomitant impacts on grazing orbits and the ecology of grasslands that may greatly threaten the sustainability of these systems.

The issues associated with adaptation options involving livestock are really no different from those of “normal” research for development, whether in a risk management or a climate-proofing framework. Decisions still have to be made concerning where to target activities, which options to assess, test and implement, and how to identify the appropriate entry points into the systems. This suggests the need for several activities, which are relevant to agricultural systems in general, not just those with livestock in them ([Table 3](#)):

- The collation of toolboxes of adaptation options and, more importantly, the identification of the domains where these may be applicable or relevant, at broad scales through the use of spatial analysis, and at more localised scales through more participatory, community-based approaches.
- The need for generic and comprehensive impact assessment frameworks has been noted in successive IPCC Assessment Reports. Such frameworks will need to be able to address the costs and benefits of different adaptation options, and they need to be comprehensive and comparable with similar efforts in other sectors such as the disaster management sector.
- Adaptation to climate change requires changes to or modifications to behaviour. Research cannot effectively contribute to the improvement of adaptive capacity without a comprehensive understanding of the context in which decisions about adaptation are made, and the capacity of decision makers to change. Adaptation may be constrained by the institutional, social, economic and political environment in which people must operate. There is an urgent need to consider developing collaborative learning processes to support the adaptation of agricultural and food systems to better cope with the impacts of climate change.

**Table 3**

Some researchable issues in the areas of frameworks and tools, adaptation and mitigation, related to livestock systems in the tropics and subtropics.

Area	Researchable issues
Methods and tools	<ul style="list-style-type: none"> <li>• Comprehensive framework development and implementation, for impact assessment and trade-off analyses</li> <li>• Tools and databases for effective targeting</li> </ul>
Adaptation	<ul style="list-style-type: none"> <li>• Which options, and where are they applicable/viable (toolboxes)</li> <li>• Information supply and demand (“Research into use”)</li> <li>• Under what conditions will specific livestock-related risk management options work?</li> </ul>
Mitigation	<ul style="list-style-type: none"> <li>• Assessment of biofuels: where and how can they contribute to poverty alleviation in livestock systems, and what are the key trade-offs in biofuels versus feed versus conservation agriculture and soil fertility management?</li> <li>• Carbon sequestration: where and how can this contribute to poverty alleviation in livestock systems, and can the associated institutional issues be addressed appropriately?</li> <li>• What are the options for mitigating the impacts of livestock on land-use change, land degradation, and other environmental services, that can also contribute to poverty alleviation (win–win situations)?</li> </ul>

## 4.2. Mitigation

Both bottom-up (specific mitigation options) and top-down (economy-wide) studies indicate that there is substantial economic potential for the mitigation of global greenhouse-gas emissions over the coming decades, that could offset the projected growth of global emissions or even reduce emissions below current levels (IPCC, 2007). All sectors could contribute, and there is “medium” agreement that agricultural practices collectively could make a significant contribution at low cost to increasing soil carbon sinks, to GHG emission reductions, and by contributing biomass feedstocks for energy use. For the medium term, various technologies are listed as being currently available and promising for their mitigation potential, including improved crop and grazing land management to increase soil carbon storage, and improved livestock and manure management to reduce methane emissions.

The total macro-economic costs in 2030 of a stabilised CO<sub>2</sub> concentration of between 445 and 535 ppm CO<sub>2</sub>-eq is put at less than 3% of GDP. This is equivalent to a global mean temperature increase at equilibrium of 2.0–2.8 °C. Concentrations would need to peak no later than 2020, and a reduction of 40–60% by 2050 of levels compared with 2000 would be needed – in other words, action over the next two decades will have a large impact on whether such stabilised levels can be achieved. For stabilisation at 500 ppm CO<sub>2</sub>-eq, carbon prices would need to be of the order of US\$ 20–80 per tonne CO<sub>2</sub>-eq by 2030, at which prices large shifts of investments into low carbon technologies could be anticipated (IPCC, 2007).

Many of the existing technological options that can mitigate GHG emissions from the livestock sector are discussed in [Steinfeld et al. \(2006\)](#). [Reid et al. \(2004\)](#) review mitigation options in the pastoral systems (LG) of the tropics. The increase in demand for livestock products will be met partly from increased productivity of livestock but also through increases in livestock populations. In terms of CO<sub>2</sub>, protection is already playing a major role for carbon sequestration in pastoral lands, particularly in Africa, where most of the protected areas are located in less productive lands. Better management of existing protected areas would improve carbon sequestration, as would efforts to slow the conversion of rangeland into cropland. As [Reid et al. \(2004\)](#) point out, this conversion can result in a 95% loss of the above-ground C and 50% loss of below-ground C. In wetter savannas, in particular, payments for maintenance of currently sequestered carbon could be quite effective. Considerable amounts of carbon can be sequestered from improved management in grasslands. Such management would include conversion of cropland to grassland, reduction in grazing intensity and biomass burning, improving degraded lands and reducing erosion, and changes in species mix. Big gains could result from converting the wetter grasslands back to woodland or forest, although gains in woodland services would have to be balanced against the loss of grassland services ([Reid et al., 2004](#)).

In terms of methane mitigation in pastoral systems, probably the only effective way is through reducing livestock numbers. It is not very likely to happen unless levels of compensation for pastoralists are high enough to offset the loss in economic, social, and cultural value. [Herrero et al. \(2008\)](#) estimate that methane emissions from domesticated ruminants in sub-Saharan Africa in LG, MR and MI systems will increase by 40% to 2030, largely as a result of increases in livestock numbers.

While technical options for mitigating emissions do exist, there are problems to be overcome related to incentive systems, institutional linkages, policy reforms, monitoring techniques for carbon stocks, and appropriate verification protocols, for example. For the pastoral lands, [Reid et al. \(2004\)](#) conclude that mitigation activities have the greatest chance of success if they build on traditional pastoral institutions and knowledge, while providing pastoralists

with food security benefits at the same time. In African smallholder systems, technical options for mitigation also exist – for example, some recent work indicates that modest changes to the MR systems in Ghana can have positive impacts on carbon sequestering ([Gonzalez-Estrada et al., 2008](#)). There is also considerable potential for some agroforestry options that can mitigate emissions while at the same time providing opportunities for increasing the resilience of agricultural systems ([Verchot et al., 2007](#)).

As for impact assessments of adaptation options, there is a real need for analytical frameworks that can examine the trade-offs involved in mitigation options. The case of biofuels is a good example of the need for such analysis. While biofuels have the potential to provide much-needed energy for industrialisation and export in developing countries, there are concerns that biofuel development could have enormous impacts on water pollution, deforestation, and food security through competition for land, water and labour. The potential opportunities for biofuel development that may increase incomes for smallholders will have to be carefully screened and the trade-offs assessed ([Dixon et al., 2009](#)). As for assessing adaptation options, this will depend on the development and application of appropriate impact assessment frameworks that can be used for such analyses. This is a critical area where progress needs to be made ([Table 3](#)), coupled with improved data collection systems in developing countries to provide adequate baseline information. The Consortium for Spatial Information of the Consultative Group for International Agriculture Research (CGIAR) is one example of a on-going, global initiative to facilitate data collection, data collation, and capacity building in developing countries, but a great deal remains to be done.

## 5. Final remarks

There is still a great deal that is not well understood concerning the interactions of climate and increasing climate variability with other drivers of change in livestock systems and in broader development trends. Multiple and competing pressures are likely on tropical and subtropical livestock systems in the future, to produce food, to feed livestock, and to produce energy crops, for example. Livestock and livestock systems are substantial users of natural resources and globally they contribute significantly to global warming, while at the same time they make contributions of critical importance to the livelihoods of at least a billion poor people in rural households, almost all of whom are in developing countries. While recent scientific assessments such as the [MA \(2005\)](#) and the [AR4 \(IPCC, 2007\)](#) represent an accurate reflection of the current state of knowledge, the yawning gaps in their treatment of livestock systems in developing countries as regards the provision of ecosystems goods and services and the maintenance of livelihoods, and how these may be affected in the future, represent an unacceptable situation. But if future scientific assessments are to do justice to the topic of livestock keepers in developing countries, then a great deal of urgent work is needed that addresses several broad issues, including the following.

First, much more clarity is needed concerning the benefits of livestock, the negative impacts they can have on greenhouse-gas emissions and the environment, and the effects of climate change on livestock systems. The regional and local variations in public goods and disbenefits associated with livestock need to be understood, before technology and policy options for adaptation and mitigation can be targeted appropriately. Much of the agricultural impacts work done to date is continental or regional in scope (e.g., [Lobell et al., 2008](#)), but such work constitutes a blunt instrument – much higher-resolution assessment will be needed if targeting is really to meet the needs of the most vulnerable people. Second, while a great deal is known about how livestock keepers cope with



climate variability, much more information is needed concerning the nature and extent of the tradeoffs possible between different crop and livestock enterprises, and between on- and off-farm income sources, in different situations. For most livestock keepers in the developing world, the variability of the weather patterns they experience is projected to increase. Changing climate variability may have critical effects on food security; in addition to impacts on food availability, variability may strongly affect the stability of food supplies and vulnerable people's ability to access food at affordable prices (Schmidhuber and Tubiello, 2007). Key to both of these broad issues will be the further development and refinement of impact assessment frameworks that can evaluate potential and implemented adaptation and mitigation options at regional and local scales, their effects on livelihoods, and the trade-offs that arise between income, food security and environmental objectives.

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