Vulnerability, Climate change and Livestock – Research Opportunities and Challenges for Poverty Alleviation

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Summary

Livestock systems in developing countries are characterised by rapid change, driven by factors such as population growth, increases in the demand for livestock products as incomes rise, and urbanisation. Climate change is adding to the considerable development challenges posed by these drivers of change. How can livestock keepers take advantage of the increasing demand for livestock products, where this is feasible, and how can the livestock assets of the poor be protected in the face of changing and increasingly variable climates? Given the complexity of livestock and crop-livestock systems, a mix of technological, policy and institutional innovations will inevitably be required. Here we outline some of the likely impacts of climate change on livestock and livestock systems, and discuss some of the resultant priority livestock development issues: water and feeds, livestock genetics and breeding, and animal health. We highlight livestock's role in alleviating poverty and helping households to deal with climate variability. However, there are considerable gaps in our knowledge of how climate change and increasing climate variability will affect livestock systems and the livelihoods of the people who depend on them. We highlight the need for detailed assessment of localised impacts, and the importance of identifying appropriate options that can help livestock keepers adapt to climate change.

1. Livestock Development Context

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). In addition, the climate is changing, and with it climate variability, and this adds to the already considerable development challenges faced by many countries in the tropics and subtropics.

The potential impact of these global drivers of change on livestock systems and the resource-poor people who depend on them is considerable. The primary focus of this paper is on the vulnerable poor in livestock systems of Asia and sub-Saharan Africa. Livestock systems in these regions have evolved based on the availability and opportunities afforded by the natural resource base. Market forces also play a major role in the evolution of livestock systems. For the purposes of this paper (and at the great risk of oversimplification) we characterize three main livestock systems:

1. **Agro-pastoral and pastoral systems** in which natural resources are constrained and people and their animals adopt adaptation strategies to meet these constraints.
2. **Smallholder crop-livestock systems** in which natural resources can be managed to intensify the productivity of the system.
3. **Industrial livestock systems,** which are highly intensive and tend not to be so tied to the local natural resource base as are the agro-pastoral and smallholder mixed systems.

The most significant trend in livestock production in developing countries is the rapid growth in demand for livestock and livestock products driven by urbanization, population growth and income increases. This so-called Livestock Revolution is largely based in developing countries (Table 1). The trends in demand will be for both increased quantity, especially as incomes rise from USD 2 to 10 per day, and for increasing quality, particularly among urban consumers who purchase livestock products from supermarkets. Clearly this increased demand is going to be met from somewhere, and the challenge for the CGIAR is to maximize the benefits to the poor in this demand-led income opportunity. Studies show that the poor are able to play a greater role in some livestock production and market chains compared with others. On the one hand, smallholders are major players in the dairy sector -- indeed, almost all the meat and milk in Africa is produced in agro-pastoral and mixed systems, for example (de Haan et al., 1997). On the other hand, industrial systems are the major actors in the rapidly growing poultry market.

For these demand-led and changing livestock systems, the focus of research that can benefit the poor needs to attend to what is changing. These changes will be influenced by both supply-side changes in natural resource use as well as market-led demand changes. Given the complexity of livestock (and in most cases crop-livestock) systems, 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. In this paper, we outline some of the likely impacts of climate change on livestock and livestock systems, and then discuss some priority livestock development issues linked to climate change that strike us as important.

2. Climate Change Context

2.1 General context for tropical livestock systems in sub-Saharan Africa and Asia

The world's climate is continuing to change at rates that are projected to be unprecedented in recent human history. The global average surface temperature increased by about 0.6 °C during the twentieth century (IPCC, 2001). According to the recent Fourth Assessment Report (IPCC, 2007), " … most of the observed increase in the globally averaged temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." The IPCC climate model projections from 2001 suggest an increase in global average surface temperature of between 1.4 to 5.8 °C to 2100, the range depending largely on the scale of fossil-fuel burning between now and then and on the different models used. At the lower range of temperature rise (1 to 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. There is reasonable agreement from a suite of different models that precipitation increases are very likely in high latitudes, while the tropics and subtropical land regions are likely to see decreases in most areas (IPCC, 2007). At the same time, weather variability is likely to increase, although with current knowledge, it is not possible to say a great deal about the extent and spatial variation of this increased variability.

The combination of generally increasing temperatures and shifting rainfall amounts and patterns will clearly have impacts on crop and livestock agriculture. Feed is and will remain a critical constraint on livestock production in the tropics and crop productivity is a useful proxy for feed availability in most regions. At mid- to high latitudes, crop productivity may increase slightly for local mean temperature increases of up to 1-3 °C, depending on the crop, while at lower latitudes, crop productivity is projected to decreases for even relatively small local temperature increases (1-2 °C) (IPCC, 2007). In the tropics and subtropics in general, crop yields may fall by 10 to 20% to 2050 because of warming and drying, but there are places where yield losses may be much more severe (Jones and Thornton, 2003; Thornton et al., 2007).

It is likely that the climate change will alter the regional distribution of hungry people, with particularly large negative effects in sub-Saharan Africa. The Fourth Assessment Report also notes that 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). Climate change impacts on agriculture are thus not only regionally distinct but also highly heterogeneous spatially. To this milieu can be added the fact that 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 undoubtedly 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. About 60% of these poor people are dependent on livestock for some part of their livelihoods (Thornton et al., 2002; Thomas and Rangnekar, 2004). Climate change is likely to have major impacts on poor livestock keepers and on the ecosystems goods and services on which they depend. 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 challenges. Developing countries are generally considered most vulnerable to the effects of climate change than more developed countries, largely because of their often limited capacity to adapt (Thomas and Twyman, 2005). It is still the case that there is only limited knowledge about the interactions of climate with other drivers of change in agricultural systems and on broader development trends. One approach to making sense of the interactions of broad development drivers, with the added burdens of climate change, is scenario building and analysis (MEA, 2005; ILRI-FAO, 2006). Such work is very difficult, given that the future is relatively unknown, but it is increasingly important as one method to evaluate how farming systems may evolve in the future, sometimes very rapidly. Part of this work necessarily 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.

2.2 Understanding climate change variability and targeting responses to benefit the poor

While the overall prognosis for climate change impacts on crop and livestock agriculture in tropical regions is not good, an even greater worry are the more substantial impacts that will occur in certain tropical locations. There is a major gap in our understanding of what these local-level impacts are likely to be. This is partly because of long-term inadequacies in Global and Regional Circulation Models, but also because of the uncertainties involved in downscaling GCM output to the high spatial resolutions needed for effective adaptation work. It is not that this downscaling cannot be done, it is just that the adequacy of it cannot currently be evaluated objectively (Henderson-Sellers, 2007).

To improve this situation, the research community is working to generate relatively high-resolution information concerning possible impacts on crop and livestock production and productivity. The first step usually involves using broad-brush approaches to identify likely “hotspots”. For example, ILRI, in concert with various partners from Africa, Asia and Europe, has identified regional "hotspots" that are already vulnerable and that are likely to suffer substantial impacts as a result of climate change. In this work, a "starting point" approach to vulnerability is taken, in which vulnerability to climate change is seen as a state that is governed not just by climate change itself but by multiple processes and stressors. This involves dealing with biophysical vulnerability, or the sensitivity of the natural environment to an exposure to a hazard; and social vulnerability, or the sensitivity of the human environment to the exposure. In such an approach, an impact is thus a function of hazard exposure and both types of vulnerability.

To identify geographic areas where climate change and subsequent impacts on crop and livestock agriculture may be relatively large, length of growing period (LGP) is a useful proxy. It is crop-independent, and it is an effective integrator of changes in rainfall amounts and patterns and temperatures. We have carried out several studies where we estimate changes in the length of growing season from current conditions to 2050, and use these changes as indicators of climate hazard for subsequent analysis. Details of the procedures used may be found in Thornton et al. (2006), but essentially, GCM output data at coarse resolution are downscaled to a higher-resolution grid using a global dataset of climate normals for the period 1960-1990 (Hijmans et al. 2005) and methods based on MarkSim, a statistical weather generator (Jones and Thornton (2000). Length of growing period is calculated using methods in Jones (1987) for current conditions, and then the process is repeated for different scenarios of future conditions; these scenarios are usually differentiated in terms of the greenhouse gas (GHG) emissions that are projected to occur during the remainder of the current century (IPCC, 2000). As an example, Figure 1 shows LGP for current conditions in Asia generated using these methods, and the percentage difference projected to occur between now and 2050, using the Hadley GCM (HadCM3) model and a high GHG-emission scenario, A1F1. These results are indicative only, but they do show that there may be considerable spatial heterogeneity of response of LGP to projected climate change. Many areas may see some expansion in growing seasons, while other areas, particularly in the tropical zones, may see contractions. These patterns arise as a result of the integration of increasing temperatures throughout the region and shifting rainfall patterns and amounts. There is a reasonable consensus between global and regional models that rainfall will increase in most of Asia during the present century, with relative increases being largest (and most consistent) in North and East Asia (Cruz et al., 2007)).

Such information can be used in various ways. In a recent study (Thornton et al., 2006), LGP change layers for Africa were combined with an agricultural systems classification, on the basis that land-use options define at least part of the livelihood strategies for millions of rural people who depend on natural resources to at least some extent for their well-being. We used a combination of the Seré & Steinfeld (1996) livestock system classification and the FAO farming systems classification (Dixon and Gulliver, 2001) to include other important communities whose livelihoods are not dependent on livestock. By overlaying the LGP changes on the agricultural systems map, it is possible to identify those systems most at risk from both positive and negative (but mostly negative) changes in LGP. Figure 2 maps the areas of Africa that are classified as LGA and MRA systems (rangeland-based arid-semiarid, and mixed rainfed arid-semiarid, respectively) projected to undergo at least a 20% reduction in LGP to 2050, using downscaled outputs from the Hadley GCM (HadCM3) model for the same two greenhouse gas emission scenarios used in Figure 1, A1F1 and B1.

Another way to utilise such information is to combine LGP change layers with vulnerability indicators. In the same study (Thornton et el., 2006), we assembled a set of proxy variables to use as indicators of biophysical and social vulnerability. These related to natural and physical capital (such as crop suitability and market access), social capital (the human poverty index and a governance index), human capital (such as stunting, infant mortality, wasting, and malaria risk), and financial capital (such as the share of total GDP associated with agriculture). An “overall” vulnerability indicator was derived using statistical clustering methods, which was then qualitatively combined with the climate change hotspot analysis (Figure 3). Results showed that many already-vulnerable regions in sub-Saharan Africa are likely to be adversely affected by climate change. These include the mixed arid-semiarid systems in the Sahel, arid-semiarid rangeland systems in parts of eastern Africa, the systems in the Great Lakes region of eastern Africa, the coastal regions of eastern Africa, and many of the drier zones of southern Africa.

Broad-scale analyses such as these are useful for helping to prioritise the allocation of research resources, but they tend to hide an enormous amount of variability concerning what may be complex responses to climate change. There is considerable heterogeneity in households' access to resources, poverty levels, and ability to cope. We are now working with various partners on what might be seen as the next stage in these analyses, where, having identified hotspots through broad-brush analysis, we are now zooming in to some of these, so that more detailed impact assessments can be carried out at the community or household level. Such work calls for different tools such as crop, livestock and household simulation models, so that the resource, economic and household well-being implications of changes in climate and climate variability can be appropriately assessed and the interactions between household enterprises (crops, livestock, off-farm income, etc) evaluated. In addition to assessing likely impacts on different crops and livestock, there is also a need for expanded efforts to assess implications on plant and animal diseases, in terms of likely changes in distribution, severity and frequency of outbreak.

3. Priority livestock development issues linked to climate change

3.1 Overall livestock and climate change considerations

The relationships between livestock populations and the environment are complex and appear to be viewed very differently from mainstream developed and developing country perspectives. A recent FAO report, *Livestock's Long Shadow*, focused on the effects of livestock on the environment (Steinfeld et al., 2006). The "long shadow" refers to the negative effects of livestock production and marketing chains on almost all aspects of the environment; livestock production is associated with carbon dioxide, methane and nitrous oxide emissions, water depletion and soil erosion as key examples. The climate change impacts of livestock production (calculated in Steinfeld et al. (2006) at 18% of the total global greenhouse gas emissions from human sources) have been widely highlighted, particularly those associated with rapidly expanding industrial livestock operations in Asia. Yet, in smallholder crop-livestock and agro-pastoral and pastoral livestock systems, livestock are one of a limited number of broad-based options to increase incomes and sustain the livelihoods of an estimated 1 billion people, who have a limited environmental footprint. Livestock are particularly important for increasing the resilience of vulnerable poor people, subject to climatic, market and disease shocks through diversifying risk and increasing assets. Given that almost all human activity is associated with GHG emissions, those from livestock in these systems are relatively modest when compared to the contribution that livestock make to the livelihoods of this huge number of people. This complex balancing act of resource use, GHG emissions and livelihoods is almost certain to get more rather than less complicated. The demand for energy supply through biofuels is yet another factor that will put increasing pressure on the natural resource base and the balance between different natural resource uses, initially, especially in mixed crop-livestock systems.

In relation to climate change, livestock will have a role in both mitigation and adaptation. Livestock mitigation measures could include technical and management options to reduce GHG emissions from livestock as well as the integration of livestock into broader environmental service approaches. These are not discussed further here. Rather, we focus on specific impacts of climate change on livestock systems and the opportunities for livestock to be a tool for helping the poor to adapt to the effects of climate change. The livestock aspects include impacts on the natural resource base supporting livestock production (largely feed and water); livestock genetic resources, breeding and management; and livestock health.

3.2 Specific livestock impacts and adaptation responses

Feeds and water

Water scarcity has become globally significant over the last 40 years or so, and is an accelerating condition for 1-2 billion people worldwide (MEA, 2005). Population growth, economic development and climate change impacts will undoubtedly have a substantial effect on global water availability in the future. The Comprehensive Assessment (CA) (2007) states that if today's food production and environmental trends continue into the future, they will lead to crises in many parts of the world. The CA calls for concerted action to improve water use in agriculture, if the freshwater challenges of future decades are to be overcome. The localised impacts of global change on water resources are starting to receive attention, but in the same way as for localised agricultural impacts, there is a great deal of work that needs to be done.

The response of increased temperatures on water demand by livestock is well-known. For *Bos indicus*, for example, water intake increases from about 3 kg per kg DM intake at 10 °C ambient temperature, to 5 kg at 30°C, and to about 10 kg at 35°C (NRC, 1981). The impacts of climate change on water supply changes in livestock systems, however, are not well-studied. The key contribution of groundwater to extensive grazing systems will probably 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 coming decades are likely to see increasing demand and competition for water in many places, and policies that can address allocation and efficiency issues will increasingly be needed.

One of the most evident and important effects of climate change on livestock production is mediated through changes in feed resources. Although indirect, effects on feed resources can have a significant impact on livestock productivity, the carrying capacity of rangelands, the buffering ability of ecosystems and their sustainability, prices of stovers and grains, trade in feeds, changes in feeding options, greenhouse gas emissions, and grazing management.

The main pathways in which climate change can affect the availability of feed resources for livestock are as follows:

1. Land use and systems changes: as temperature increases and rainfall increases or decreases (depending on location) and becomes more variable, the niches for different crops and grassland species change. For example, transitions from one crop to another, or between crops and rangelands, can occur. As temperate areas become warmer, substitution for crop species more suited for warmer climates can occur (for instance, maize in parts of Asia in places where only wheat would grow in the past). In parts of East Africa, reductions in the length of growing period are likely to lead to maize being substituted by crop species more suited to drier environments such as sorghum and millet (Thornton et al., 2007). In marginal arid places of southern Africa where crops grow, 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 (van Rooyen, personal communication). 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.

2. Changes in the primary productivity of crops, forages and rangelands: this is probably the most visible effect of climate change on feed resources for ruminants. However, the effects are significantly different depending on location, production system and on crop and pasture species. In C4 species, increases in temperature up to 30-35 °C will in general increase the productivity of crops, fodders and pastures, as long as the ratio of evaporation to potential evapotranspiration and nutrient availability do not significantly limit plant growth. These effects are mediated primarily through increases in the maximum rates of photosynthesis and rates of leaf appearance and extension, which lead to higher leaf area indexes and therefore higher rates of net assimilation (Johnson and Thornley, 1985). Tiller recruitment is also affected by temperature. In C3 plants such as rice and wheat, temperature effects have a similar effect but increases in CO_2 levels will also have a significant (positive) impact on the productivity of these types of crops (IPCC, 2007). For food-feed crops, since harvest indexes change with the amount of biomass produced, the end result for livestock production is a change in the quantity of grains and stovers and availability of metabolisable energy for dry season feeding. An example is presented in Table 2 for the production of maize stover in East Africa, using CERES-Maize, a crop simulation model (Ritchie et al., 1998), two General Circulation Models and two contrasting climate change scenarios. This simple analysis (Herrero, Thornton and Notenbaert, unpublished) shows clearly that the aggregated effects for the window as a whole are very modest. The impacts in particular places, however, may be very much larger (both positive and negative), in terms of the number of animals that could be supported on dry-season maize stover.

Climate change effects will also be observed in rangelands. In the semi-arid rangelands of the Sahel, for example, where the ratio of actual to potential evapotranspiration limits plant growth (Le Houérou et al., 1988) and LGP may decrease significantly, rangeland productivity is likely to decrease. Such changes could have enormous impacts on the livelihoods of pastoralists dependent on these rangelands through the numbers of animals that they can keep, livestock productivity, potential loss of animals during the dry season, and longer transhumance routes in search of feed for animals, for example.

3. Changes in species composition. Species composition in rangelands and some managed grasslands is an important determinant of livestock productivity. As temperature and CO_2 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. For example, in the temperate regions and subtropics, where grasslands often contain C3 and C4 species, some species are more prominent than others in the summer, while the balance of the mix reverts in winter. Small changes in temperature alter this balance significantly and often result in changes in livestock productivity; an implication of this is that significant changes in management of the grazing system may be required to attain the production levels desired. It has also been suggested recently that the proportion of browse in rangelands will increase in the future as a result of increased growth and competition of browse species due to increased CO_2 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 patters of the communities dependent from them. Legume species will also benefit from increases in CO_2 and in tropical grasslands, the mix between legumes and grasses could be altered.

4. Quality of plant material. It has been shown that 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 smallholders. At the same time, the interactions between primary productivity and quality of grasslands will demand modifications in grazing systems management to attain production objectives.

It is apparent that the impacts of increasing temperatures and CO_2 concentrations, together with shifting rainfall distributions and amounts, may play themselves out in complex ways in relation to feed resources. While a great deal is known about the general impacts on plant growth processes, less is known about the effects in specific situations and how these may affect livestock and the people who depend on them.

Livestock genetics and breeding

Livestock genetic adaptation responses will vary from intensifying and managed systems to adaptive systems in more marginal environments. Traditionally, the selection of animals in tropical breeds has been an adaptive one, but in recent times, market pull has stimulated a rapidly changing demand for higher production that could not be met quickly enough by breed improvement of indigenous animals. Widespread cross-breeding of animals, mostly with “improver” breeds from temperate regions, crossed with local animals, has occurred – often with poor results. Little systematic study has been conducted on matching genetic resources to different farming and market chain systems from already adapted and higher producing tropical breeds. However, given the even greater climatic variability and stresses anticipated, this is a most logical response to the adaptive challenges that will be faced.

The greatest role for using adaptive traits of indigenous animal genetic resources will be in more marginal systems in which climatic and other shocks are more common. Indigenous breeds, which have co-evolved in these systems over millennia and have adapted to the prevalent climatic and disease environments, will be essential (Baker and Rege, 1994). These systems are under substantial pressure arising from the need for increased production as well as land-use changes. Under these circumstances, ensuring continuing availability of these adapted animal breeds to meet the needs of an uncertain future is crucial. The adaptive challenge will be to improve productivity traits while maintaining adaptive traits. This co-evolution will take place at different speeds within different systems. Within this context, there will be a constant need to improve productivity since increasing demand will need to be supplied from a relatively non-increasing land and water resource base. Current animal breeding systems are not sufficient to meet this need and the improvement of breeding programs under different livestock production and marketing contexts is a critical area for new research.

The preservation of existing animal genetic diversity as a global insurance measure against unanticipated change has not been as well appreciated as has that for plants. When conservation through use is insufficient (as is the widespread situation with indiscriminant cross-breeding), *ex –situ*, especially *in vitro*, conservation needs to be considered as an important component of a broad-based strategy to conserve critical adaptive genes and genetic traits. The science for this has improved significantly in recent years and many developed countries are establishing national cryo-banks. However, most developing countries do not have the financial nor technical capacity to establish and maintain such cryo-banks. Given the complexities associated with the establishment and maintenance of such facilities, it makes sense to consider a similar approach as has been taken for plants and to create international banks such as the *In-Trust* plant collections in the CGIAR gene banks. Such gene banks would act both as an insurance policy as well as a source of genetic material for breed improvement programs.

Livestock (and Human) Health

The major impacts of climate change on livestock and human diseases have been on diseases that are vector-borne. Increasing temperatures have supported the expansion of vector populations into cooler areas, either into higher altitude systems (for example, malaria and livestock tick-borne diseases) or into more temperate zones (for example, the current outbreak of bluetongue disease in northern Europe). Changes in rainfall pattern can also influence an expansion of vectors during wetter years. This may lead to large outbreaks of disease, such as those seen in East Africa due to Rift Valley Fever virus, which is transmitted by a wide variety of biting insects.

The potential complexity of climate change influences with other factors associated with vector populations is well illustrated by the distribution of tsetse flies in sub-Saharan Africa (McDermott et al., 2001). Tsetse flies transmit African trypanosomes widely in livestock (ruminants, equids, and pigs). Tsetse are very sensitive to environmental change, either due to climate or direct human impacts on habitat but the impacts of major species groups vary. Forest and riverine species are much more sensitive to climatic factors that savannah species while riverine species are much more adaptable to increasing human population densities than the other groups. Predictions of climate and population change on tsetse density indicates that tsetse populations and animal trypanosomosis will decrease most in semi-arid and sub-humid zones of West Africa and in many but not all areas of Ethiopia and eastern and southern Africa (see Figure 4) through a combination of population pressure on savannah species and climate change pressure on riverine species. The animal trypanosomosis situation in the humid forest zones of central and western Africa will be less changed. Sleeping sickness, particularly the gambiense type, will continue, as now, to be a major problem, if concerted control efforts are not implemented.

Beyond vector-borne diseases, helminth infections, particularly of small ruminants will be greatly influenced by changes in temperature and humidity. Climate changes could also influence disease distribution indirectly through changes in the distribution of livestock. Areas becoming more arid would only be suitable for camels and small ruminants. If these species are forced to aggregate around water points, the incidence of parasitic diseases could increase.

The most important adaptive trait of tropical livestock is disease resistance. Two of the most important resistance traits have been for trypantolerance in African ruminants and helminth resistance, particularly in certain breeds of sheep across tropical and temperate regions. Particularly for trypanotolerant breeds, climate change may decrease the importance of this trait in subhumid zones of West Africa. One potential danger is that if climatic changes lead to selection against trypanotolerance in the short to medium term that these adaptive traits that have developed over millennia will be lost if future conditions lead to greater disease risk in the longer-term.

Climatic changes, mediated through changes in crop and livestock practices, could also influence the distribution and impact of several diseases such as malaria across most systems and schistosomiasis and lymphatic filariasis in irrigated systems (Patz and Confalonieri, 2005). Climate change is bound to have further impacts on heat-related mortality and morbidity and on the incidence of climate-sensitive infectious diseases (Patz et al., 2005), and these may be considerable. While climate change impacts may have few direct impacts on other diseases such as HIV/AIDS, climate variability impacts on food production and nutrition can affect susceptibility to HIV/AIDS as well as to other diseases (Williams, 2004). Changing disease burdens are bound to add considerably to the development problems caused by successive natural disasters and emergence from conflict, associated with low levels of adaptive capacity (Brooks et al., 2005).

4. Livestock's role as an adaptation tool, and research needs

A changing climate and increasing climate variability are clearly going to have considerable impacts through a wide range of mechanisms on people whose livelihoods depend at least in part on livestock. Some of the mechanisms have been outlined above. Particularly in pastoral and agropastoral systems, livestock are key assets held by poor people, providing multiple economic, social, and risk management functions. Livestock are a crucial coping mechanism in variable environments, and as this variability increases they will become more important. There is a growing body of literature on the role of livestock in providing pathways out of poverty for poor households. Climate-induced shocks often result in negative coping strategies that deplete livestock assets (Freeman et al., 2007). For many poor people the loss of livestock assets means collapsing into chronic poverty with long-term effects on their livelihoods or ability to climb up the poverty ladder. Other studies show that diversification of income sources through livestock farming can be a key strategy for escaping poverty (Krishna et al., 2004; Kristjanson et al., 2004). This highlights the importance of securing the livestock assets of poor households in the face of increasing variability. Despite the role that livestock have been shown to play in coping with risk and providing livelihood options, as noted above there is still only limited knowledge about the interactions of climate with other drivers of change in livestock-based systems and on broader development trends. This is an imbalance that needs to be rectified, and some of the CGIAR centres are already addressing this imbalance. For example, ILRI and CIAT are undertaking work to identify much more specifically those areas of Africa where changing climate and climate variability are likely to make any crop production increasingly difficult. In such places, livestock keeping is likely to be one viable option for maintaining household food security in the face of increasing climate variability. Another example is the Harvest Plus Challenge Programme, which is assessing the present-day location of crop breeding and testing sites, in terms of their suitability for likely future conditions. Similar work is planned in relation to livestock feed resources. Clearly, to cope with more extreme environments in the future, adaptation options need to be tested in more extreme environments now, particularly if there are substantial lead times involved, as in the case of breeds and varieties (Jones et al., 2007).

A wide range of possible adaptation or coping options exists, from technological changes to increase or maintain productivity, through to learning, policies and investment in specific sectors and risk reduction options, which may increase the adaptive capacity of poor livestock keepers. Kurukulasuriya and Rosenthal (2003) have defined a typology of adaptation options:

- 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.
- Market responses that are potentially effective adaptation measures to climate change, such as insurance and credit schemes and income diversification opportunities.
- Institutional and policy changes, such as the removal or putting in place of subsidies, the development of income stabilization options, improvements in agricultural markets, and the promotion of inter-regional trade in agriculture.
- Technological developments, such as the development and promotion of new crop varieties, improvements in water and soil management, and improved animal health technology.

Given the considerable range of options available, however, one of the research needs associated with both crop- and livestock-mediated adaptation options are methods and tools to assess what may be appropriate where. This includes things such as the collation of toolboxes of adaptation options and the identification of the domains where these may be applicable or relevant, at broad scales through the use of spatial GIS analysis, and at more localised scales through more participatory, community-based approaches.

Another critical need is the development of collaborative learning processes to support the adaptation of livestock systems to better cope with the impacts of climate change. Research cannot hope to contribute to improving adaptive capacity without a comprehensive understanding of the context in which decisions about adaptation are made and of the capacity of decision makers to change. Farmers already have a wealth of indigenous knowledge on how to deal with climate variability and risk. However, there is still a need to assess these adaptation options in relation to reducing vulnerability of humans and ecosystems, particularly options associated with livestock, with the object of maintaining or increasing food security, incomes and resilience while maintaining key ecosystem functions. Such assessment needs to be done in conjunction with well-targeted capacity building efforts to help farmers deal with changes in their systems that go beyond what they have experienced in the past.

There is a growing consensus that adaptation to climate change in the short- to medium-term is perhaps best framed within the context of overall risk management and enhancing resiliency. Washington et al. (2006) argue that particularly in Africa, addressing climate change will depend on a close engagement with climate variability -- "... 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." The underlying rationale for a risk management approach is the simple observation 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 to bring the issues associated with climate change to the "here and now". Helping decision makers to 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. Nevertheless, adaptation is always constrained by the institutional, social, economic and political environment in which people must operate, and these constraints need to be addressed in any comprehensive risk management approach.

In summary, the livestock development issues raised by climate change can perhaps be best characterised as follows: they are highly intertwined, they are complex, some of the possible impacts at broad scales are reasonably well-researched while others are not, and currently many of the agricultural and other impacts at local scales are simply not known. How these impacts may combine to affect household vulnerability, and how adaptive capacity may be most effectively increased, are critical issues that need considerable attention. Although a lot of work on a wide array of adaptation options is being undertaken, 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). As many people have pointed out, there are many factors that will determine whether specific adaptation options are appropriate and viable in particular locations. Understanding what these factors are and where they operate is key to identifying vulnerable households and implementing adaptation options that can maintain or raise incomes and household food security. In many of these places, livestock will have a critical role to play.

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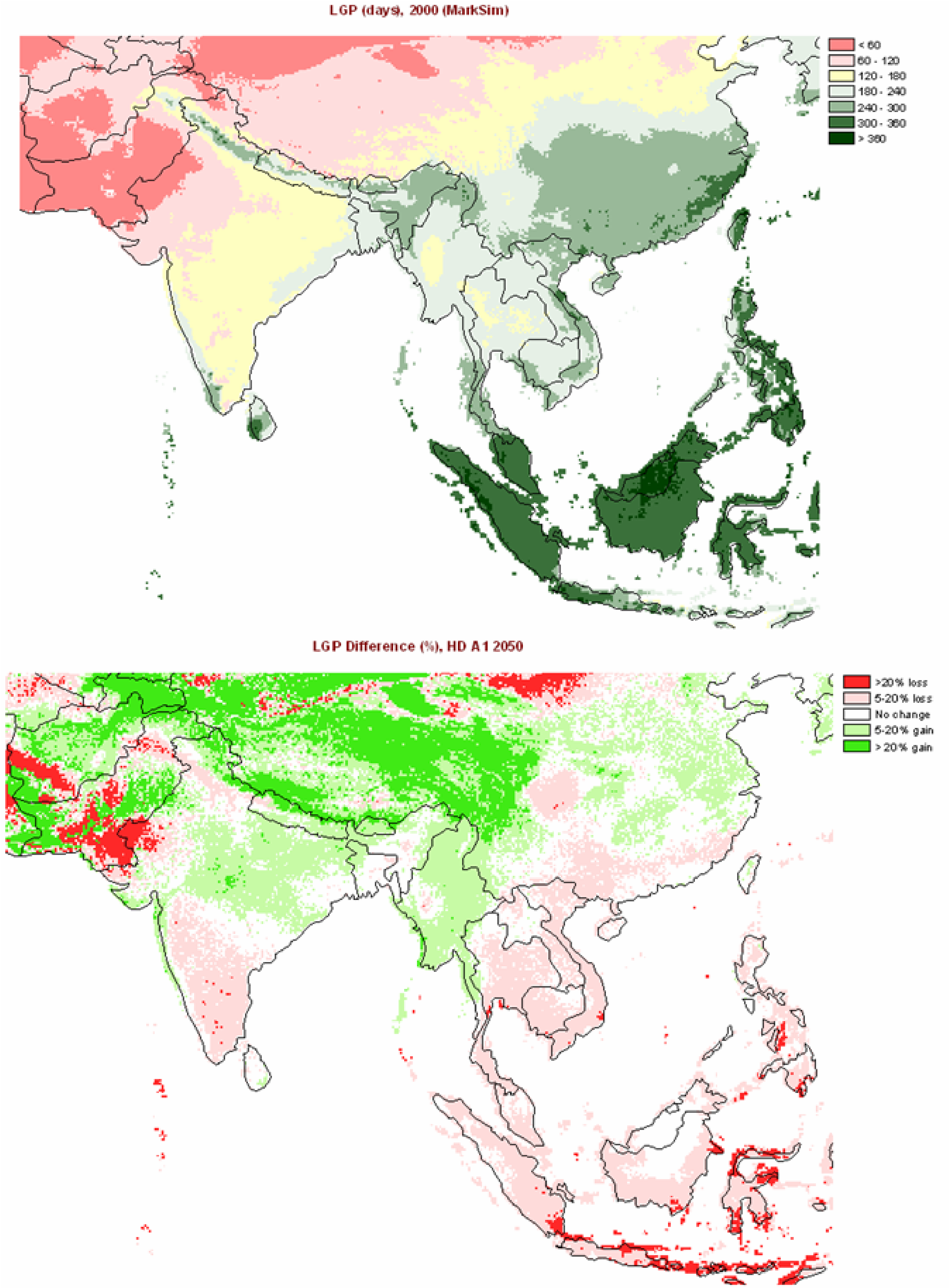
Figure 1. Top, Current length of growing period (LGP) in Asia, estimated using MarkSim. Bottom, % change in LGP to 2050, HadCM3, A1F1 (a high-emissions scenario).



LGP (days), 2000 (MarkSim)

LGP Difference (%), HD A1 2050

Figure 2. Areas within the LGA and MRA systems projected to undergo >20% reduction in LGP to 2050: HadCM3, A1 (left), B1 (right).). LGA, rangeland-based arid-semiarid system. MRA, mixed rainfed arid-semiarid system. Source: Thornton et al. (2006).

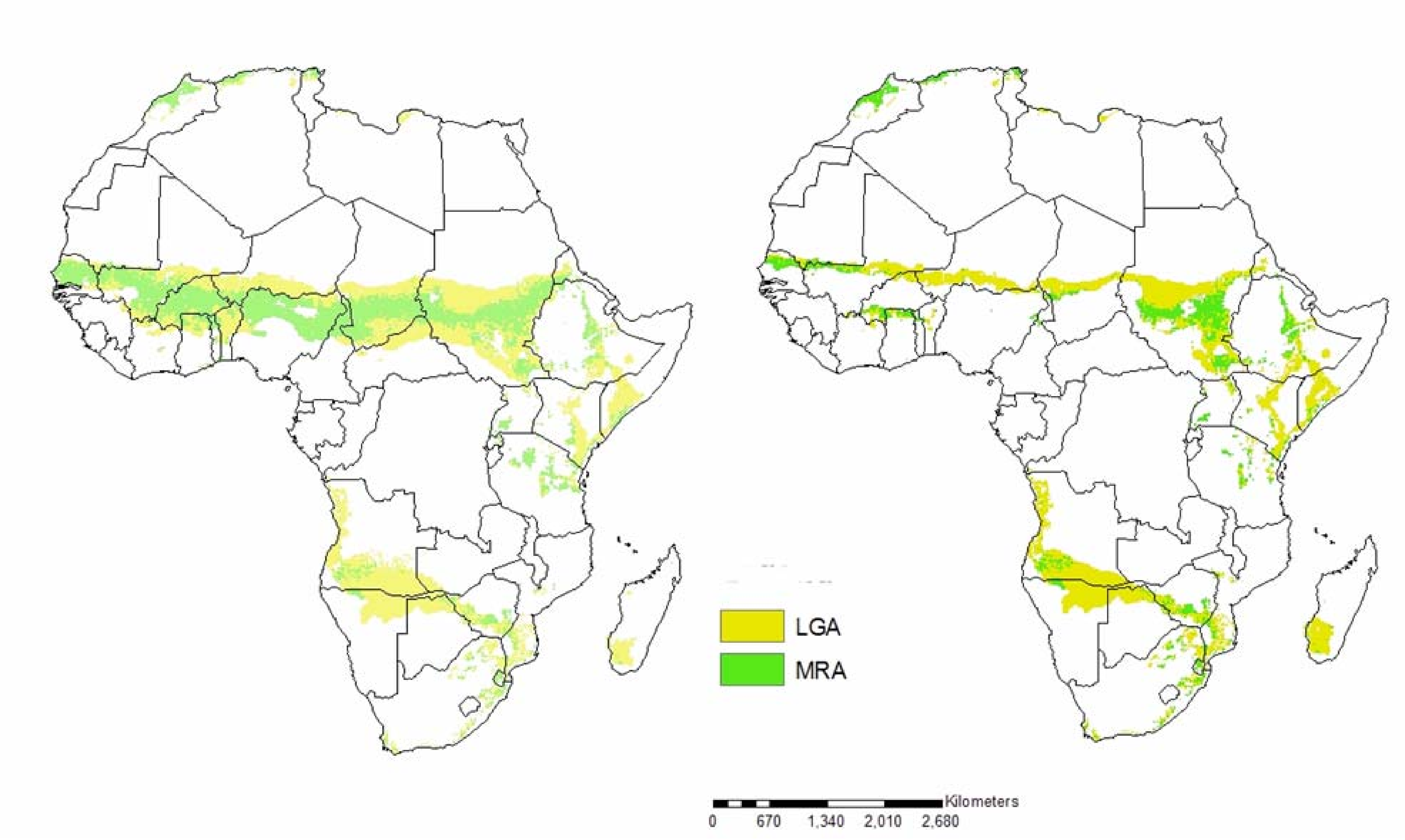


Figure 3. Country-by-systems in sub-Saharan Africa, showing quartiles of an indicator of vulnerability to climate change (quartile 1, "less vulnerable" – quartile 4, "more vulnerable"). From Thornton et al. (2006).

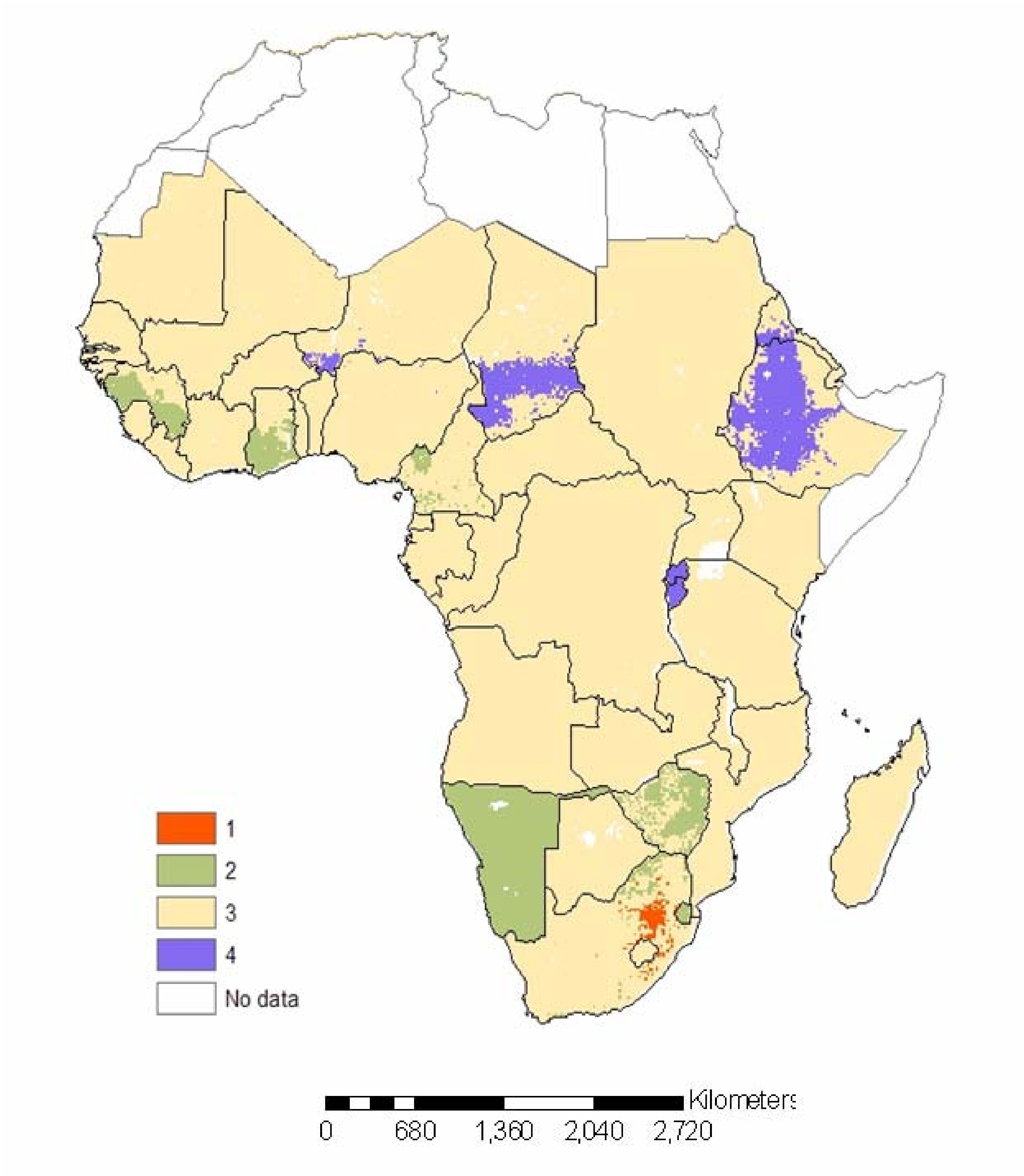


Figure 4. Model predictions compared to current distribution of Morsitans (top left), Fusca (center left) and Palpalis (bottom left) tsetse groups and predicted changes in distribution to 2050. Morsitans (top right), Fusca (center right) and Palpalis (bottom right). From McDermott et al. (2001).

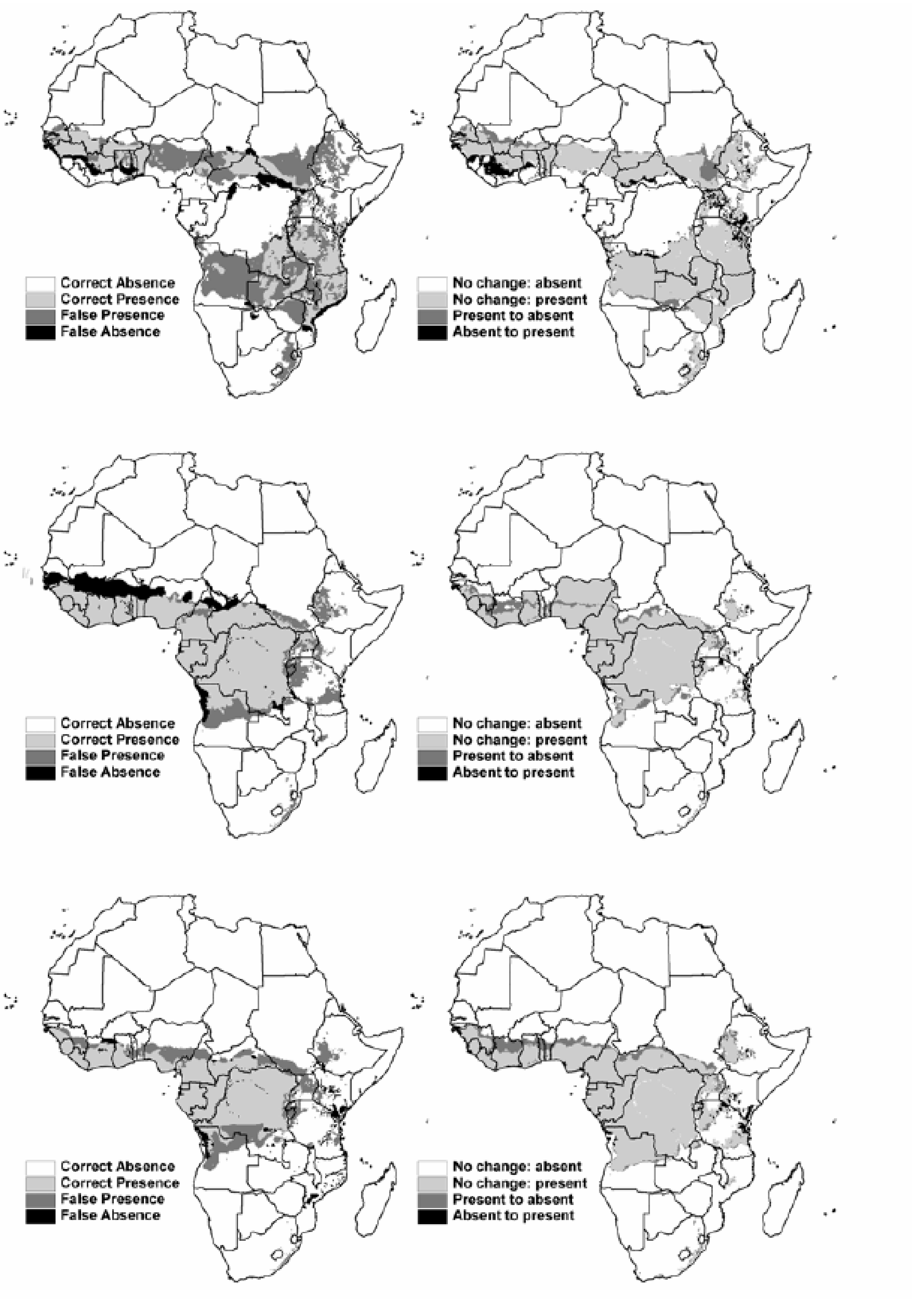


Table 1. Increase in total annual meat[1] and milk[2] consumption[3] 1982 to 2020, actual and predicted

(millions of metric tons)

	Actual change 1983 to 2003	Projected change 2003 to 2020	Levels in 2003
Developed countries			
Bovine + Sheep/Goat Meat	-2	+6	33
Poultry + Pig Meat	+21	+4	74
Dairy (LME)	+34	+18	268
Developing countries			
Bovine + Sheep/Goat Meat	+22	+14	42
Poultry + Pig Meat	+71	+50	101
Dairy (LME)	+101	+152	223
World meat (mmt)	+112	+74	250
World milk (mmt LME)	+134	+170	491

[1] Meat = beef, pork, mutton and goat, and poultry.

[2] Milk = all dairy consumed as human food except butter in liquid milk equivalents

[3] Consumption = direct use as food, uncooked weight bone-in.

Sources: Increases in total annual meat consumption between 1983 and 1997 are based on differences between annual three-year annual averages based on the year shown, calculated from FAOStat (FAO various years). The meat figures for 2003 are derived from preliminary worksheets obtained form the FAO commodities division. The milk figures pertain to 2002. The 2020 projections are from the July 2002 version of Mark Rosegrant's IMPACT model (Rosegrant et al. 2001; Delgado 2005).

Table 2. Effects of different climate change scenarios (A1 and B1), as simulated by two climate models (ECHam4 and Hadley CM3) on the production of maize stover in East Africa (Herrero, Thornton and Notenbaert, unpublished)

	Baseline	**ECHam4**		**Hadley CM3**	
		A1FI	**B1**	**A1FI**	**B1**
	2000	**2030**	**2030**	**2030**	**2030**
Above-ground Biomass (MT)	47,470	49,311	49,004	50,228	49,560
Grain (MT)	14,125	15,137	15,075	15,506	15,286
Stover (MT)	33,345	34,174	33,929	34,722	34,274
Ruminants (# in LU)	20,818,330				
Digestible dry matter	18,340	18,796	18,661	19,097	18,851
Metabolisable energy (ME, '000 MJ)	273,429	280,227	278,218	284,720	281,047
ME Differences ('000 MJ)	0	6,798	4,789	11,291	7,618
Additional number of animals able to be maintained		745	525	1237	835

For the area between longitudes 28 to 42 °E and latitudes 12 °S to 6 °N.

LU maintenance, 25 MJ ME per LU per day, or 9125 MJ per LU per year.

Scenario A1FI is a high-emission scenario, B1 is a lower-emission scenario (IPCC, 2000).

The analysis assumes that maize is grown in all areas except on soils classified as "agriculturally unsuitable" and in areas where the length of growing period (2000) is less than 40 days per year.