The livestock–climate–poverty nexus

A discussion paper on ILRI research in relation to climate change

Discussion Paper No. 11

PK Thornton, J van de Steeg, A Notenbaert and M Herrero

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For further information please contact p.thornton@cgiar.org

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Summary

Climate change will have severe impacts in many parts of the tropics and subtropics. 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 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. Evidence is being assembled that the temporal and spatial heterogeneity of household responses 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 very serious problems for many other households. Furthermore, ruminant livestock themselves have important impacts on climate, through the emission of methane and through the land-use change that may be brought about by livestock keepers.

Given that climate change is now being seen as a key development challenge, and that a very large global community is already working on climate-change-related issues, the CGIAR in general, and ILRI in particular, need to consider carefully how the research agenda might be adjusted to respond. While the global environmental change community is very large, ILRI as a small institute can still contribute effectively to the climate change / development debate by focusing on a few key niches, through alliances with carefully chosen collaborators. This discussion paper is an attempt to assemble and summarise relevant information concerning climate change, livestock and development, and to identify what these key niches might be.

The report briefly summarises what is known about climate change and its effects on agro-ecosystems, and summarises the current limits to prediction. It reviews the literature on climate change impacts on livestock and livestock impacts on climate, and thus sets out to answer the question, what do we know? Knowledge and data gaps are then identified, and a synthesis presented in relation to our clients and stakeholders and to alternative providers of knowledge and information. The paper ends by looking at the questions, what do we not know, and what should we do about it, with a discussion of recommendations for ILRI activities in the area, and the strategic alliances needed, some of which already exist.

1 Introduction

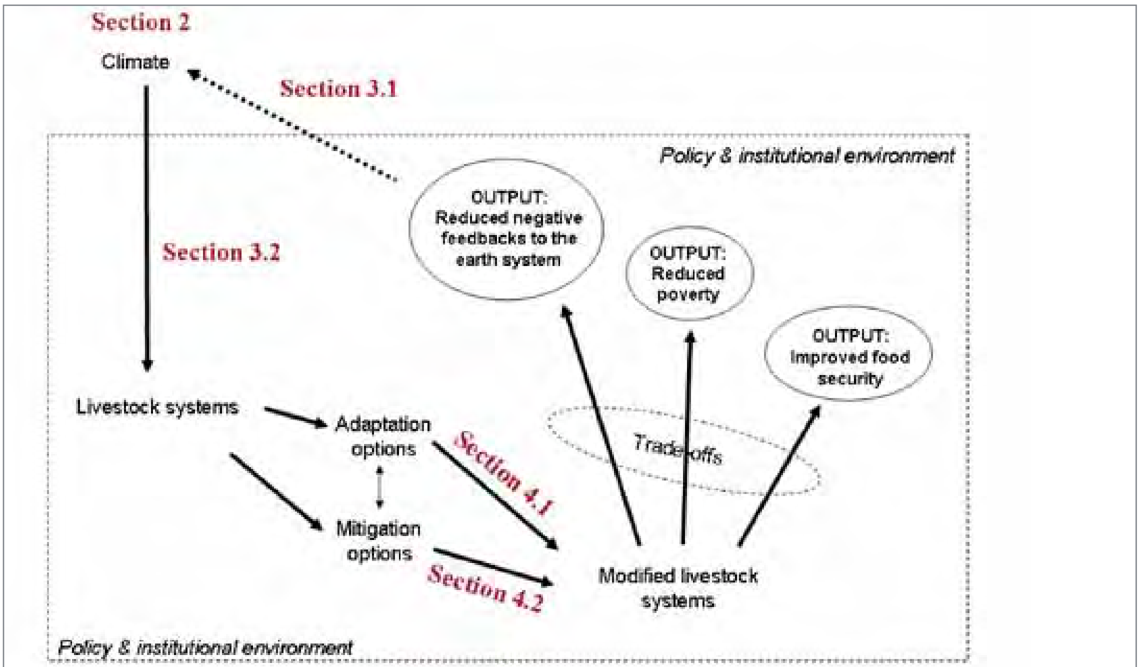
Humans have always lived with changing climate. Indeed, the movement of all human species from Africa to the rest of the globe has only been possible at all because of brief periods of warming that seem to occur every 100,000 years or so. At the times of these "interglacial maxima", the Sahara and Sinai deserts become verdant and allow migratory movement across what has normally been desert for the last 2 million years. When modern humans finally spread out of Africa to Asia and the rest of the planet starting about 85,000 years ago, sea level was from 60 to 100 m below current levels — we are all descended from just one group of ancestors who made the break (Oppenheimer, 2003). The story of human settlement and of human evolution is thus very much tied to the fact that earth's climate has always been changing, and will continue to do so. Taking a paleoclimatic view of climate change, we are still living in the after-glow of the last interglacial maximum, and ironically enough, recent anthropogenic warming impacts on the climate are slowing down the reversion to what has been the norm for most of the last 2 million years — our present ice epoch, the Pleistocene (Oppenheimer, 2003).

Climate change has thus ever been with us. The issue is that recent changes are such as to render the speed of change much greater now than in the past, and that despite the chaos in weather systems and the feedbacks, the impacts are going to be felt by us all. The most recent "best estimates" of temperature increases from the IPCC are in the range 1.8 to 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. There is considerable uncertainty associated with such estimates, and some suggest 6 to 8 °C temperature increases during the current century (Lovelock, 2006; Stainforth et al., 2005). The impacts of temperature increases at even the lower end of the IPCC (2007) likely range will be far-reaching, and there is currently considerable discussion as to the likelihood of rapid changes (tipping points) in the earth-climate system such that even relatively small temperature changes could have catastrophic impacts (Schellnhuber et al., 2006). No-one is seriously proposing that warming is not already occurring, or that it is not going to continue for the time being. There is, of course, considerable uncertainty as to its ultimate extent. While the media is often full of the so-called "debate" as to the causes of this warming, the consensus among the people who understand the dynamism and complexity associated with ocean-atmospheric systems (i.e. the scientists involved) is that there is no credible, scientific basis for rejecting the role of humans as being an important cause.

This discussion paper is an attempt to highlight what is known about the likely impacts of climate change on the people who are the targets of ILRI's research and development activities — resource-poor livestock keepers in the developing world. The object of this is to help inform the debate as to what should or could ILRI be doing in the area of climate change work, that could add value to the large amounts of work already being carried out by the Global Change community. The document highlights several points. The first point is that most of the climate change impact assessment work that has been done to date on agricultural ecosystems has referred to crops, rather than to livestock or to livestock feed resources. Second, the regional heterogeneity of climate change impacts is very great, and these impacts are essentially to the detriment of the tropics rather than the temperate areas of the planet. This raises a moral issue, of course, since it is countries in the temperate zones who are largely responsible for the GHG emissions that are driving these changes in climate. Third, in terms of what can be done about it, both mitigation and adaptation are required, although possibly in different places and across different time scales. Fourth, while ILRI is but a small player in an international context, the direct importance of livestock to the livelihoods of at least 600 million poor people in the tropics and subtropics (Thornton et el., 2002) ups the ante, and there are several areas of livestock-related research in which ILRI with strategic partners could play a key role. It would seem that there are not that many international players in the livestock - poverty - climate change arena, and this does present opportunities.

The structure of the paper is overlaid on the conceptual framework shown in Figure 1. This attempts to show the relationship among climate, systems, adaptation and mitigation options, and outputs, and is a modified version of the framework produced for the third draft of the Concept Note for a Climate Change Challenge Programme developed in May 2007. "Livestock systems" is short-hand for livestock-based production systems, livestock product systems (processing and distribution etc), and livelihood systems that include livestock components. Section 2 summarises the current state of knowledge of climate change, drawing heavily on the Fourth Assessment Report of the IPCC (2007), and touches on the limits to predictability of current climate models. In section 3, the role of livestock in climate change is very briefly discussed (section 3.1), followed by a discussion of the impacts of climate change on various aspects of livestock systems (section 3.2). Section 4 considers some of the livestock-related responses to climate change, not so much in terms of a review of options (this has been done by several people already), but more in terms of possible researchable issues related to adapting to climate change (section 4.1) and to mitigating the livestock-related impacts on climate change (section 4.2). Section 5 attempts to identify gaps and opportunities for ILRI's research portfolio, and summarises some promising areas of work that may be worth pursuing in the next few years.

Figure 1. Conceptual framework showing the relationship between climate, systems, adaptation and mitigation options, and outputs. Red numbers refer to the relevant sections of the paper. Modified from a diagram produced for the third draft of the Concept Note for a Climate Change Challenge Programme, May 2007.



2 Climate change and its impacts

2.1 Observed changes

The first sentence in the "Summary for Policy Makers" of the Fourth Assessment Report (hereafter referred to as AR4) of the IPCC (2007) reads as follows:

"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level."

Global mean surface temperature has increased with a linear trend of 0.74 °C over the last 100 years (Figure 2). Eleven of the past twelve years to 2006 rank among the 13 warmest years on record. The warming is widespread over the globe, with a maximum at higher northern latitudes. Consistent with warming, mountain glaciers and snow cover declined in both hemispheres. Global average sea level has risen since 1961 at an average rate of 1.8 mm per year and since 1993 at 3.1 mm per year, with contributions from thermal expansion, melting glaciers and ice caps, and the Greenland and Antarctic ice sheets.

Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia in recent decades. The frequency of heavy precipitation events has increased over most land areas; again, this is consistent with warming and increases of atmospheric water vapour. At the same time, there has been some drying in the Sahel, the Mediterranean, southern Africa and parts of southern Asia.

Widespread changes in extreme events have been observed. For example, cold days, cold nights and frosts are less frequent, while hot days, hot nights, and heat waves are more frequent. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. There is also observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970.

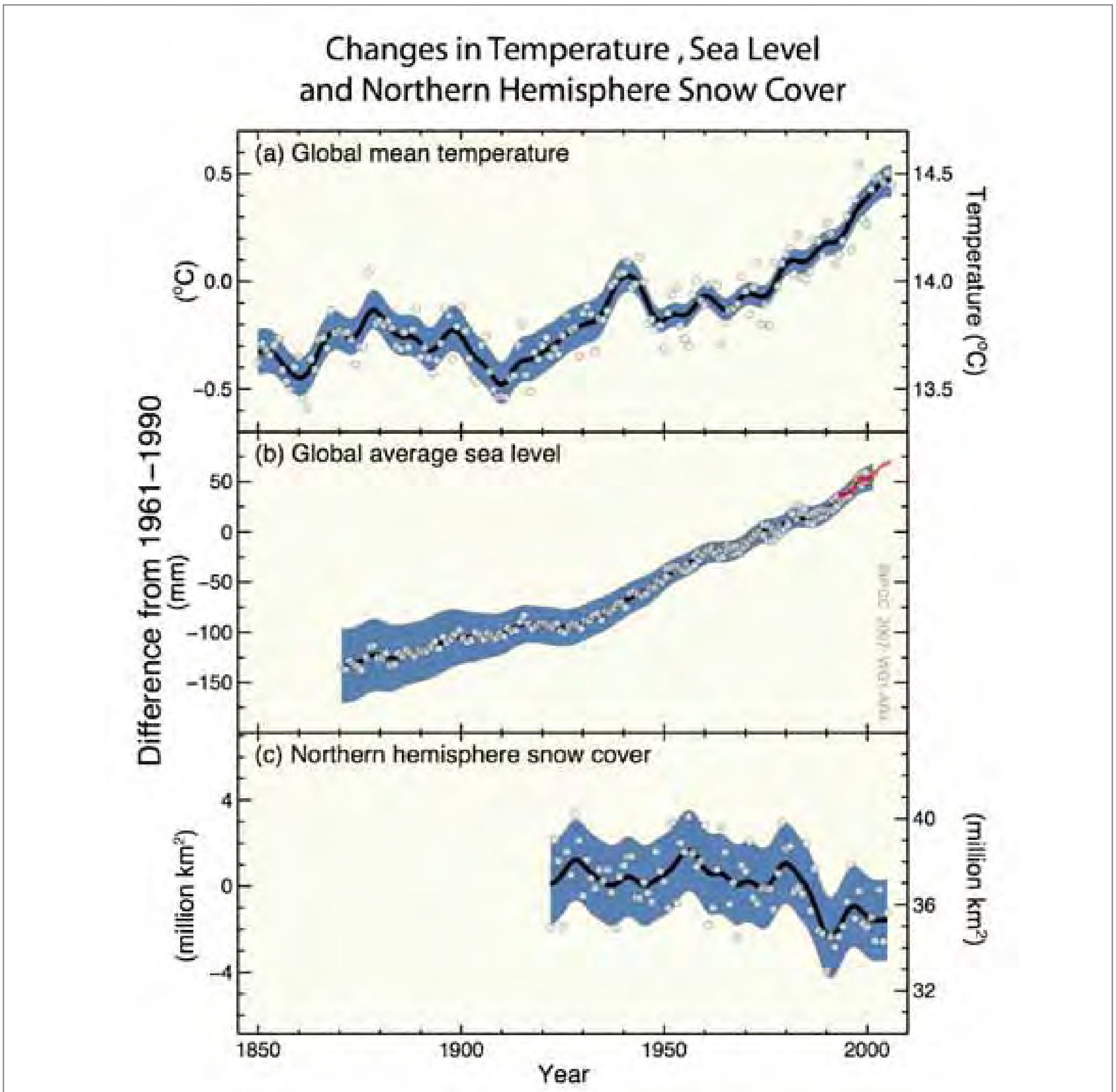
Paleoclimatic information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1,300 years. The last time the polar regions were significantly warmer than at present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea-level rise.

In terms of the causes of these changes, global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentrations are primarily due to increasing emissions from fossil fuel use and land-use change. Increases in methane and nitrous oxide are primarily due to agriculture. Most of the observed increase in globally-averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. It is extremely unlikely that the global temperature change of the past fifty years can be explained without external forcing. During this time, the sum of solar and volcanic forcings would be likely to have produced cooling, not warming. The observed patterns of warming and their changes over time are simulated only by models that include both natural and anthropogenic forcings (see Figure 3).

2.2 What may happen in the future?

Current climate models indicate that continued greenhouse gas emissions at or above current rates will cause further warming and induce many changes in the global climate system during the 21st century, and these are very likely to be larger than those observed during the 20th century. For the next two decades, a warming of about 0.2°C per decade is projected under a range of emission scenarios. In fact, even if the concentrations of all greenhouse gases and aerosols is kept constant (miraculously) at year 2000 levels, a further warming of about 0.1°C per decade would still be expected.

Figure 2. Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). (IPCC, 2007)



Beyond the next couple of decades, projections of what may occur depend increasingly on socio-economic scenarios and the resulting emissions pathways. To look at longer term impacts of GHG emissions on climate, IPCC (2007) and many other studies, for that matter, make use of a set of "possible futures" originally developed by Nakicenovic and others, the SRES scenarios (Special Report on Emissions Scenarios, IPCC (2000)). These depict possible emission trends under a wide range of economic, social and technological assumptions. They are defined in relation to two basic axes (Figure 4), as to whether the world envisaged is globalised or localised, and as to whether economic or environmental criteria dominate the development agenda. Some key features of the four families of SRES scenarios are outlined in Table 1.

Figure 3. Attribution of climate change to specific causes. Climate models are important tools for attributing and understanding climate change. Understanding observed changes is based on the best understanding of climate physics, as contained in climate models. Observed global, annual mean temperature over the 20th century (black line) is compared with that simulated by a wide range of these models. (a), individual model simulations and their overall mean (thick line) that are driven by external influences including increases in greenhouse gases, in aerosols, in changes in solar radiation, and by volcanic eruptions. The observations rarely leave the range of model simulations. The trends and individual cooling events in response to volcanic eruptions are reproduced well. The fuzzy range gives an idea of the uncertainty associated with the variability in the climate system. (b) shows model simulations with just solar and volcanic forcings. IPCC (2007).

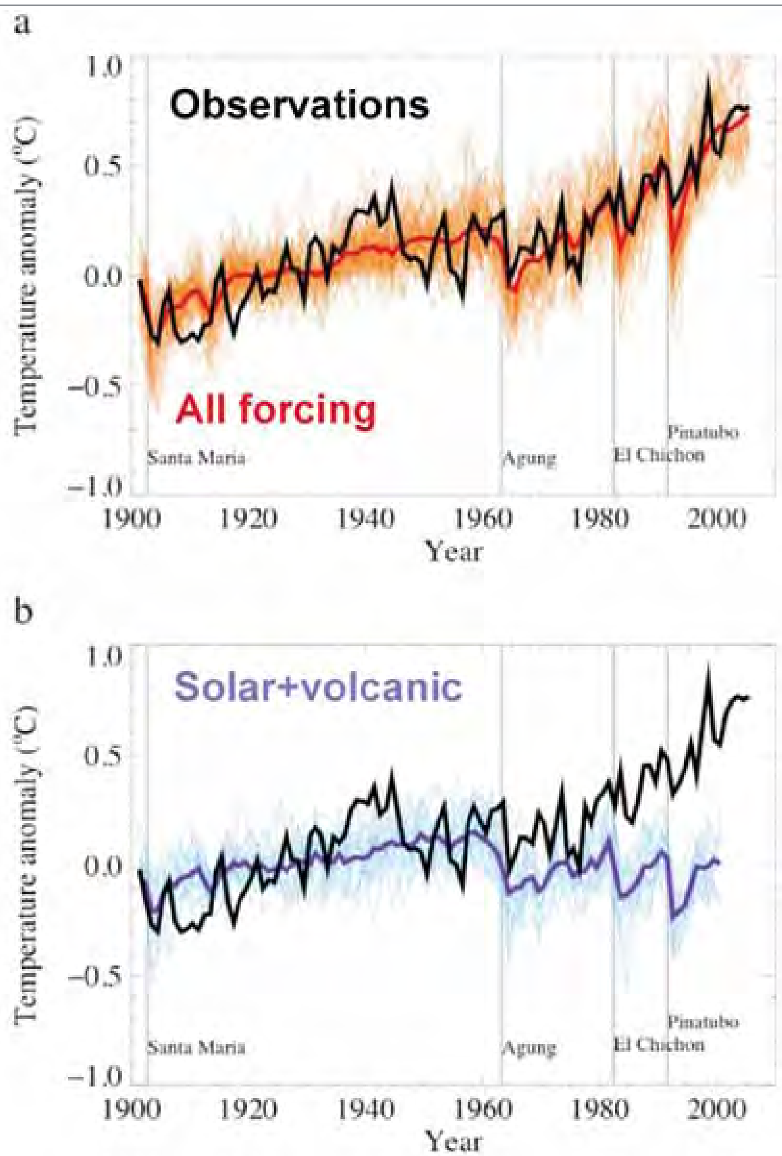
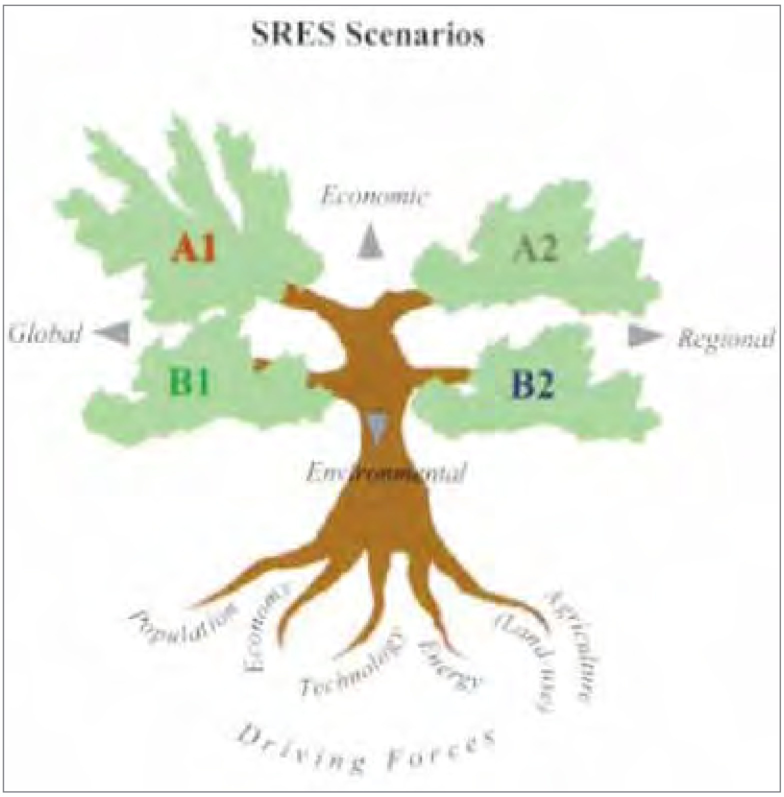


Figure 4. The two axes of the SRES scenarios: global versus regional, economic versus environmental. (IPCC, 2000).



These scenarios result in atmospheric concentrations of CO_2 of 540–970 parts per million in 2100. This range of projected concentrations is primarily due to differences among the emissions scenarios. Model projections of the emissions of other greenhouse gasses (mainly CH_4 and N_2O) also vary considerably by 2100 across the IPCC-SRES emissions scenarios. Table 2 lists the best estimates and assessed likely uncertainty ranges of projected warming for the end of the 21st century for each of the six SRES so-called “marker” scenarios, as well as model-based projections of sea-level rise. Temperatures are also shown in Figure 5.

In terms of the patterns of warming, there is now some consensus between the various Atmosphere-Ocean General Circulation Models (AOGCMs) that projected warming during the current century is expected to be greatest over land at high northern latitudes, and least over the Southern Ocean and parts of the North Atlantic Ocean (Figure 6). These geographical patterns of warming are similar to those observed in recent decades. In terms of rainfall, rainfall increases are very likely in high latitudes, while decreases are likely in most subtropical land regions (Figure 7). Again, this continues observed patterns in recent trends.

The AR4 confirms that it is very likely that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent. It is likely that future tropical cyclones will become more intense, with larger peak wind speeds and more heavy precipitation. As noted above, anthropogenic warming and sea-level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized tomorrow.

Table 1. The Emissions Scenarios of the Special Report on Emissions Scenarios (SRES) (IPCC, 2000)

A1. The A1 storyline and scenario family describe a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describe a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

B1. The B1 storyline and scenario family describe a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describe a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Table 2. Projected globally averaged surface warming and sea level rise at the end of the 21st century. For explanations of scenarios, see Table 1. From IPCC (2007).

	Temperature Change *(°C at 2090-2099 relative to 1980-1999)*		Sea Level Rise *(m at 2090-2099 relative to 1980-1999)*
Case	Best estimate	Likely range	Model-based range *excluding future rapid dynamical changes in ice flow*
Constant Year 2000 concentrations	0.6	0.3 - 0.9	–
B1 scenario	1.8	1.1 - 2.9	0.18 - 0.38
A1T scenario	2.4	1.4 - 3.8	0.20 - 0.45
B2 scenario	2.4	1.4 - 3.8	0.20 - 0.43
A1B scenario	2.8	1.7 - 4.4	0.21 - 0.48
A2 scenario	3.4	2.0 - 5.4	0.23 - 0.51
A1FI scenario	4.0	2.4 - 6.4	0.26 - 0.59

The AR4 documents the fact that there is now higher confidence in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation, and some aspects of extremes and of ice. It also notes that more complete attribution of observed natural system responses to anthropogenic warming is prevented by short time scales of many impact studies, greater natural climate variability at regional scales, and possible contributions of non-climate factors in some regions. There are very few studies that directly link observed effects with global climate model simulations. For precipitation, climate models can currently provide insight into overall global and regional trends but cannot provide accurate estimates of future precipitation patterns when the landscape plays an important role (as in the case of mountainous or hilly areas). A typical result of climate models is that approximately three quarters of the land surface has increasing precipitation.

Figure 5. Multi-model global averages of surface warming (relative to 1980-99) for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for an experiment where concentrations were held constant at year 2000 values. The bars to the right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. IPCC (2007).

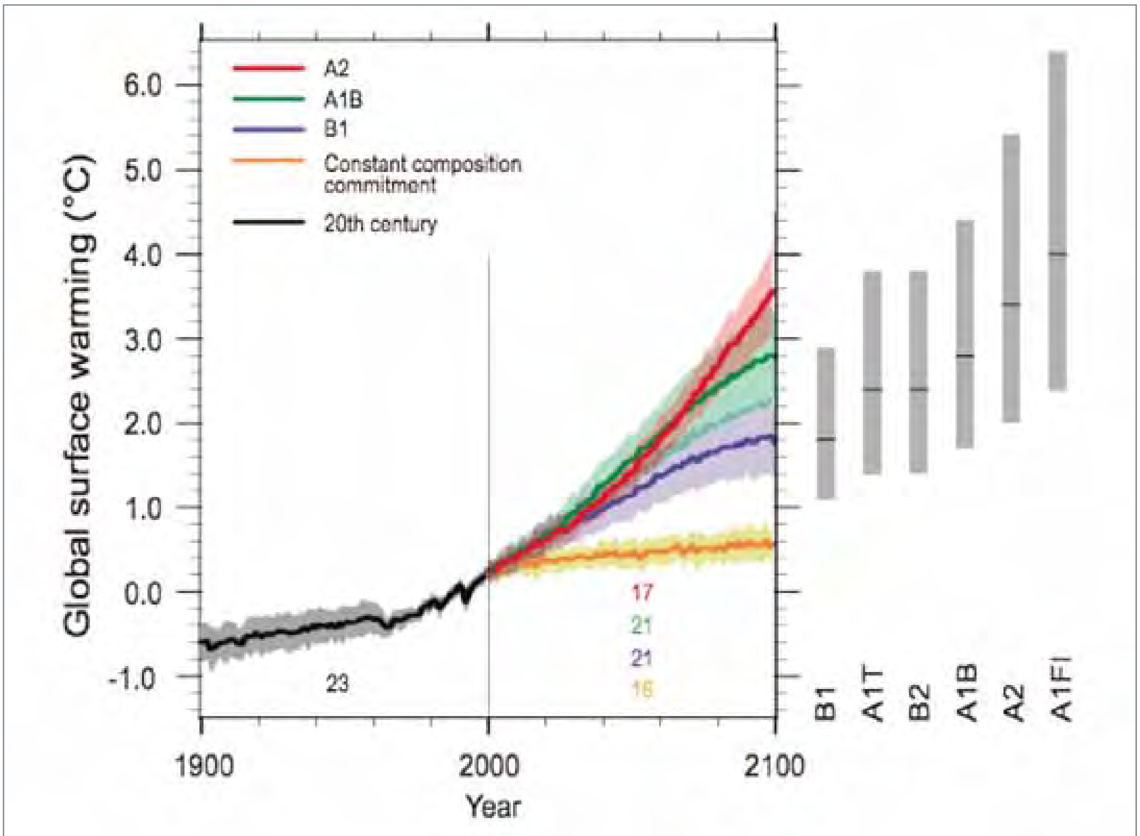


Figure 6. Projected surface temperature changes for the late 21st century (2090-2099) relative to the period 1980–1999. The maps show the multi-AOGCM average projections for the B1, A1B and A2 SRES scenarios (IPCC, 2007).

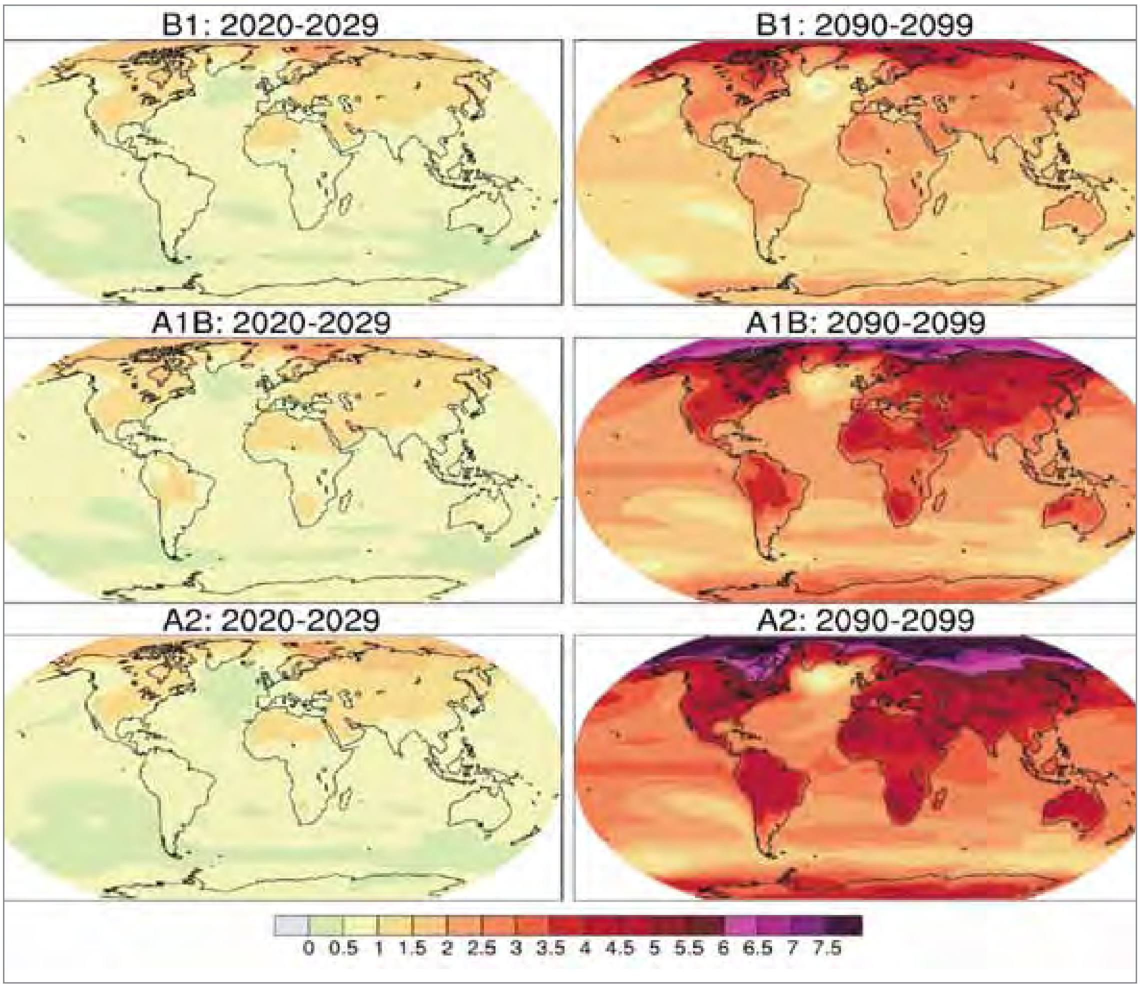
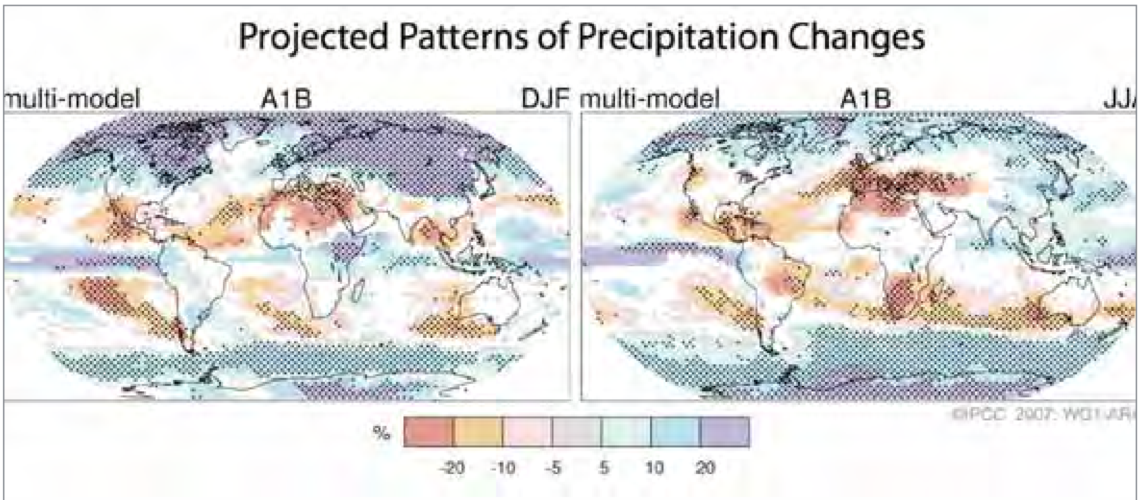


Figure 7. Relative changes in precipitation (in percent) for the period 2090-2099 relative to 1980-1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left panel) and June to August (right panel). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change (IPCC, 2007).



However, some arid areas may become even drier, including the Middle East, parts of China, southern Europe, the northeast of Brazil, and west of the Andes in Latin America. This will increase water stress in these areas. Although climate models do not agree on the spatial patterns of changes in precipitation, they do agree that global average precipitation will increase over the twenty-first century. This is consistent with the expectation that a warmer atmosphere will stimulate evaporation of surface water, increase the humidity of the atmosphere, and lead to higher overall rates of precipitation. In general, climate models give a more consistent picture for temperature change than for precipitation (see IPCC, 2007).

Table 3 presents a summary of the regional responses of temperature, rainfall and extreme events in Africa, Asia and Central & South America, as laid out in the AR4 (Christensen et al., 2007), together with its likelihood (very likely or likely). This table includes only those statements that are made in the regional summary, and the implication is that there is much less consensus between the various climate models as to other phenomena that are not mentioned there. As noted above, there is considerable regional variation in uncertainty in these patterns.

Table 3. Regional climate change projections from AR4 (Christensen et al., 2007).

	Africa	Asia	Central and South America
Temperature	Warming **very likely** to be larger than the global annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics.	Warming **likely** to be well above the global mean in central Asia, the Tibetan Plateau and northern Asia, above the global mean in eastern Asia and South Asia, and similar to the global mean in Southeast Asia.	Annual mean warming **likely** to be similar to the global mean warming in southern South America but larger than the global mean warming in the rest of the area.
Rainfall	Annual rainfall **likely** to decrease in Mediterranean Africa and northern Sahara. Rainfall in southern Africa **likely** to decrease in much of the winter rainfall region and western margins. **Likely** increase in annual mean rainfall in East Africa. Unclear how rainfall in the Sahel, the Guinean Coast and the southern Sahara will evolve.	Precipitation in boreal winter is **very likely** to increase in northern Asia and the Tibetan Plateau, and **likely** to increase in eastern Asia and southern parts of Southeast Asia. Precipitation in summer is **likely** to increase in northern Asia, East Asia, South Asia and most of Southeast Asia, but is **likely** to decrease in central Asia.	Annual precipitation **likely** to decrease in Central America and southern Andes (large local variability in mountains). Winter precipitation in Tierra del Fuego, summer precipitation in south-eastern South America, **likely** to increase. Uncertain how mean rainfall will change over northern South America, including the Amazon forest. Some qualitative consistency in some areas: rainfall increasing in Ecuador and northern Peru; decreasing in southern NE Brazil.
Extreme events	Increase in dry spells **likely** in most subtropical areas.	**Very likely** that hot spells in summer will be longer, more intense and more frequent in East Asia. Fewer very cold days are **very likely** in East Asia and South Asia. **Very likely** an increase in frequency of intense precipitation events in South and East Asia. Extreme rainfall and winds associated with tropical cyclones are **likely** to increase in East Asia, Southeast Asia and South Asia.	Increase in dry spells **likely** in most subtropical areas.

2.3 Likely impacts

Impacts of climate change can vary greatly due to the development pathway assumed, such as estimates of regional population, changes in income levels, and degree of technological development. These (and other factors) are strong determinants of vulnerability to climate change. For example, the number of people whose food supply, flood risk or water scarcity would be affected by climate change strongly depends on the assumed size of the vulnerable low-income population. Some future impacts already appear unavoidable, owing to the inertia of the climate system. This suggests that even under stringent mitigation scenarios some future impacts are already unavoidable. These would include decreased water availability and increased drought risk in the tropics and subtropics, and increased coastal damage from floods combined with sea-level rise, for example.

IPCC (2007) identifies particularly vulnerable systems and sectors, and these include the following:

- Low-lying coastal regions due to the threat of sea-level rise and increased risk from extreme weather events;
- Water resources in the dry tropics and subtropics due to decreases in rainfall and higher rates of evapo-transpiration;
- Agriculture in low-latitude regions due to reduced water availability;
- Human health in areas with low adaptive capacity.

Particularly vulnerable regions include:

- Africa, especially the sub-Saharan region, because of current low adaptive capacity.
- Small islands, due to high exposure of population and infrastructure to sea-level rise and increased storm surges.
- Asian megadeltas due to large populations and high exposure to sea-level rise, storm surges and river flooding.

The likely impacts of climate change on agriculture are regionally highly distinct. In general terms, global food production may increase with increases in local average temperatures over the range 1 to 3 °C, but above this, it may decrease (IPCC, 2007). At mid- to high latitudes, crop productivity may increase slightly for moderate (1-3 °C) local mean temperature increases, depending on the crop, while at lower latitudes, crop productivity is projected to decrease 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% by 2050 because of warming and drying, but there are places where yield losses may be much more severe, even catastrophic (Jones and Thornton, 2003; Thornton et al., 2008).

It is thus highly likely that climate change will alter the regional distribution of hungry people, with particularly large negative effects in sub-Saharan Africa. The Fourth Assessment Report 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. 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).

2.4 The limits to prediction

The future is of course inherently unknowable and unpredictable. In relation to climate change work in general, there are two overarching areas of uncertainty. One relates to how human development will unfold in the coming decades, and the second to what is actually knowable about the climate system and how it will respond to human agency and the other drivers that govern it. The first of these is often dealt with using scenarios of the future, or “plausible futures” — different sets of assumptions about how human development will proceed in the future, linked to global drivers such as economic growth, technological change, population growth, etc. A lot of work has been done on scenario development for several reasons, including identifying knowledge gaps, understanding the significance of uncertainties, illustrating what is possible and what is not possible, and identifying what strategies might work in a range of possible scenarios. The emission scenarios of the IPCC have already been referred to above (see Table 1). Some other widely-used scenarios include those of the Millennium Ecosystem Assessment, which developed four scenarios that describe the consequences of different development pathways for ecosystem services and human well-being. The scenarios were designed to explore contrasting transitions of society, as well as contrasting approaches to policies for managing ecosystem services. These scenarios are described in great detail in MA (2005). Some of the key features are shown in Table 4. Another recent set of scenarios (which are somewhat related to the MA scenarios) was developed for GEO4 (2007), and these are designated “markets first”, “policy first”, “security first”, and “sustainability first”. Scenario development and analysis is very challenging, but can help provide extremely useful information for assessing likely impacts of change in relation to specific drivers, as one step in the process of determining possible courses of action in an unknowable future. The MA scenarios have been used at ILRI as a framework for starting to think about the future development of the livestock sector in the coming decades (Freeman et al., 2007), and there is a great deal more useful work that can be done with this kind of scenario analysis.

The second overarching area of uncertainty, the issue of what is actually knowable about the climate system and how it will respond to the drivers that govern it, is in many ways more problematic. There are various sources of uncertainty with regard to climate projections; over several decades, some of this uncertainty arises because of unknown future forcing by solar output, volcanic eruptions, rates of ocean heat uptake, and human activity affecting the

Table 4. Some of the main assumptions about indirect and direct driving forces across the four MA scenarios (MA, 2005)

	Global Orchestration	Order from Strength		Adapting Mosaic	TechnoGarden
Indirect Driving Forces					
		Industrial Nations[a]	**Developing Nations**[a]		
Demographics	high migration; low fertility and mortality levels; 2050 population: 8.1 billion	relatively high fertility and mortality levels (especially in developing countries); low migration, 2050 population: 9.6 billion		high fertility level; high mortality levels until 2010 then to medium by 2050; low migration, 2050 population: 9.5 billion	medium fertility levels, medium mortality; medium migration, 2050 population: 8.8 billion
Average income growth	high	medium	low	similar to Order from Strength but with increasing growth rates toward 2050	lower than Global Orchestration, but catching up toward 2050
Investments into human capital	high	medium	low	begins like Order from Strength, then increases in tempo	medium
Overall trend in technology advances	high	low		medium-low	medium in general; high for environmental technology
International cooperation	strong	weak—international competition		weak—focus on local environment	strong
Energy demand and lifestyle	energy-intensive	regionalized assumptions		regionalized assumptions	high level of energy-efficiency
Direct Driving Forces					
Land use change	global forest loss until 2025 slightly below historic rate, stabilizes after 2025; ~10% increase in arable land	global forest loss faster than historic rate until 2025, near current rate after 2025; ~20% increase in arable land compared with 2000		global forest loss until 2025 slightly below historic rate, stabilizes after 2025; ~10% increase in arable land	net increase in forest cover globally until 2025, slow loss after 2025; ~9% increase in arable land
Greenhouse gas emissions by 2050	CO_2: 20.1 GtC-eq CH_4: 3.7 GtC-eq N_2O: 1.1 GtC-eq other GHGs: 0.7 GtC-eq	CO_2: 15.4 GtC-eq CH_4: 3.3 GtC-eq N_2O: 1.1 GtC-eq other GHGs: 0.5 GtC-eq		CO_2: 13.3 GtC-eq CH_4: 3.2 GtC-eq N_2O: 0.9 GtC-eq other GHGs: 0.6 GtC-eq	CO_2: 4.7 GtC-eq CH_4: 1.6 GtC-eq N_2O: 0.6 GtC-eq other GHGs: 0.2 GtC-eq
Air pollution emissions	SO_2 emissions stabilize, NO_x emissions increase from 2000 to 2050	both SO_2 and NO_x emissions increase globally		SO_2 emissions decline; NO_x emissions increase slowly	strong reductions in SO_2 and NO_x emissions
Climate change	2.0°C in 2050 and 3.5°C in 2100 above pre-industrial	1.7°C in 2050 and 3.3°C in 2100 above pre-industrial		1.9°C in 2050 and 2.8°C in 2100 above pre-industrial	1.5°C in 2050 and 1.9°C in 2100 above pre-industrial
Nutrient loading	increase in N transport in rivers	increase in N transport in rivers		increase in N transport in rivers	decrease in N transport in rivers

[a] "Industrial " and "developing " refer to the countries at the beginning of the scenario; some countries may change categories by 2050.

[1] "Climate variability refers to variations in the mean state and other statistics (such as standard deviations,the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability)." Glossary of Terms used in the IPCC Fourth Assessment Report, online at http://www.ipcc.ch/glossary/index.htm--

[2] "Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings,or to persistent anthropogenic changes in the composition of the atmosphere or in land use." Glossary of Terms used in the IPCC Fourth Assessment Report, online at http://www.ipcc.ch/glossary/index.htm

composition of the atmosphere and feedbacks from the land surface (Wilby, 2007). Over the next four decades, global mean temperature rise is largely insensitive to differences among emission scenarios (Stott and Kettleborough, 2002).

But it is evident that present and future predictability of climate variability[1] and climate change[2] is not the same everywhere, and that gaps in knowledge of basic climatology are revealed by a lack of agreement between climate models in some regions (Wilby, 2007). While there is now higher confidence in projected patterns of warming and sea-level rise, there is less confidence in projections of the numbers of tropical storms and of regional patterns of rainfall over large areas of Africa, south Asia and Latin America (see Figure 7). As the IPCC (2007) points out, this underscores the importance of using different scenarios and different models to assess likely climate changes and their impacts.

There are at least two more problems associated with current knowledge of climate and climate modelling. The first has a direct bearing on our lack of understanding of what the local-level impacts of climate change are likely to be. This relates to 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 its adequacy cannot currently be evaluated objectively (Henderson-Sellers, 2007). Indeed, at the present time, there are real doubts as to whether the quality and quantity "... of regionalized model projection is adequate to support the specific and detailed information needed for adaptation purposes. In order to meet adaptation needs, the underlying climate science and models will need to be improved; regionalization techniques evaluated and improved; and access skills will need to be strengthened, especially in vulnerable areas" (Henderson-Sellers, 2007).

The second problem relates to the significant gap that exists between the information that we currently have at seasonal time scales and the information we have at "climate-change" time scales (2050 and beyond) — information about what is likely over the next three to 20 years is largely missing (Washington et al., 2006). This presents a critical problem, as this time scale is vital for political negotiation, for assessing vulnerability and the relationship with the Millennium Development Goals, and for agricultural planning, etc. While users of climate risk information are most interested in the next few decades, the global climate of the coming decades will be dominated by natural variations from year to year and from decade to decade arising from the chaotic nature of ocean-atmosphere interactions, changes in the output of the sun, and the amount of aerosol injected into the stratosphere by explosive volcanic eruptions (Wilby, 2007). The human signal, though detectable and growing, is a relatively small component of the change.

It is likely to be many years before these issues are addressed satisfactorily. Climate science has a long way to go. In the meantime, there are various things that can be done: the development of the scientific and economic capacity to better understand and cope with existing climate variability (Washington et al, 2006); and the development of climate forecast tools and data sets that capture incremental changes in risk over the scales needed for adaptation planning (Wilby, 2007). But the current limits to prediction constitute a substantial stumbling block in understanding local impacts of climate change over the short- to medium-term and thus in assessing the efficacy and appropriateness of different adaptation and mitigation options in specific situations.

3 Impacts of livestock on climate, and of climate change on livestock

This section summarises the role of livestock in climate change, in terms of their contribution to greenhouse gas emission. This is followed by a brief review of what is known concerning the impacts of climate change on livestock under the headings feeds (quantity and quality), heat stress, water, diseases and disease vectors, biodiversity, systems, and indirect impacts. Of course, many of these relationships are two-way (e.g. livestock have obvious impacts of 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.

3.1 Livestock's impact on climate

Overall, livestock activities are estimated to contribute some 18% to total anthropogenic greenhouse gas emissions, taking the five major sectors for greenhouse gas reporting: energy, industry, waste, land use + land-use change + forestry, and agriculture (Steinfeld et al., 2006). Livestock account for nearly 80% of all emissions from the agricultural sector. The three major greenhouse gases here are carbon dioxide, methane, and nitrous oxide.

Increasing carbon dioxide concentrations have had more impact on historical radiative forcing (i.e. heating) than any other greenhouse gas (MA, 2005). It has other impacts too: it has a fertilizing effect on many plants, and its rapid injection into the atmosphere causes acidification of the ocean, with negative effects for organisms such as coral (MA, 2005). Annual net additions of carbon to the atmosphere are in the range 4.5 to 6.5 billion tonnes. Most of this can be attributed to the burning of fossil fuel and land-use changes. There are various drivers of these factors, such as population growth, economic growth, technological change, and primary energy requirements (IPCC, 2000). While the respiration of livestock makes up only a very small part of the net release of carbon to the atmosphere, other livestock-related factors play a much greater role. These include the fossil fuels used to manufacture the mineral fertilizer used in feed production, in feed and animal production, and in the processing and transportation of livestock products, livestock-related land-use changes, and land degradation that may be attributable in part to livestock (Steinfeld et al., 2006). Taken together, livestock may account for 9% of global anthropogenic emissions of carbon dioxide. There is considerable uncertainty in such estimates, however, owing to the difficulties of estimating losses from such sources as deforestation and pasture degradation. There is also considerable variation between types of farming system and regions. As farming systems become more intensive and industrialised in places, CO_2 emissions will increase, corresponding to increasing shifts away from the solar energy harnessed by photosynthesis to fossil fuels (Steinfeld et al., 2006).

Another greenhouse gas is methane, which like CO_2 has a positive radiative forcing on climate — the global warming potential of methane is 21-times that of CO_2 over 100 years (UNFCCC, 2007), although it is much shorter-lived in the atmosphere. It also has impacts on high-atmosphere ozone formation. Current atmospheric concentration of CH4 is more than twice that of preindustrial times (MA, 2005). Livestock account for 35-40% of global anthropogenic emissions of methane, via enteric fermentation and manure, which together account for about 80% of agricultural emissions (Steinfeld et al., 2006). In terms of livestock production, the relative importance of ruminants globally is likely to decline in the future, coupled with a move towards high productivity, and Steinfeld et al. (2006) do not anticipate increases in enteric fermentation in the future (methane emissions from animal manure are much lower). However, as with CO_2, there are considerable system and regional differences. Recent estimates by Herrero et al. (2008) indicate that methane emissions from African cattle, goats and sheep are likely to increase from their current level of about 7.8 million tonnes of methane per year in 2000 to 11.1 million tonnes per year by 2030, largely driven by increase in livestock numbers. Again, there are considerable differences in methane emission per tropical livestock unit (TLU, 250 kg bodyweight), depending on production system and diet, from 21 (less productive systems) to 40 (more productive systems) kg per TLU per year.

The third important greenhouse gas is nitrous oxide, which is a powerful, long-lived gas (its global warming potential is 310-times greater than CO_2 over a 100-year time horizon) (UNFCCC, 2007). Atmospheric concentrations are some 16% above the levels in preindustrial times. In addition to its radiative forcing characteristics, nitrous oxide has impacts on stratospheric ozone depletion. Ecosystem sources (mostly soil micro-organisms in a wide variety of environments) account for about 90% of all emissions (MA, 2005). Increased emissions are driven largely by fertilizer use, agricultural nitrogen fixation, and atmospheric nitrogen deposition. Livestock activities contribute substantially, and account for some 65% of global anthropogenic emissions (75-80% of agricultural emissions). Emissions of N_2O originating from animal manure are much higher than any other N_2O emission caused by the livestock sector, and these emissions are dominated by mixed crop-livestock systems (Steinfeld et al., 2006).

To summarise (see Table 5), livestock contribute substantially to global emissions of greenhouse gases, which in turn have direct impacts on the climate via warming of the atmosphere, with consequent, complex interactions on rainfall amounts and patterns. There are, however, very large differences in greenhouse gas emissions between different systems, regions, and levels of intensification.

Table 5. Livestock's contribution to greenhouse gas emissions (from Table 7.1 in Steinfeld et al., 2006).

Parameter	Value	Comments
Livestock's contribution to climate in change in CO_2 equivalent	18 percent	Including pasture degradation and land-use change
Livestock's share in carbon dioxide emissions	9 percent	Not considering respiration
Livestock's share in methane emissions	37 percent	
Livestock's share in nitrous oxide emissions	65 percent	Including feed crops

3.2 Climate change's impacts on livestock

This section contains an overview of the impacts of climate change on livestock, organised under seven headings: feeds, quantity and quality; heat stress; water; livestock diseases and disease vectors; biodiversity; livestock systems; and indirect impacts.

Feeds, quantity and quality

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_2 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 DM yields;
- greater incidences of drought, which may offset any DM yield increases;
- great intensity of rainfall, which may increase N leaching in certain systems.

The impacts of increased atmospheric CO_2 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 (Rotter and van de Geijn, 1999). The result is that, 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_3 plants, but there is also a small effect for C_4 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_3 crops may be of the order of 20-30% at elevated CO_2 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) now suggest that results from such studies, carried out under more realistic conditions, indicate that the CO_2 fertilisation effect may be only half that estimated from enclosure studies. If this is so, then this would cast serious doubts on projections that indicate that rising CO_2 concentrations will offset the losses caused by temperature and rainfall effects on the yields of C_3 crops. In response to the Long et al. (2006) paper, however, 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_2 of the magnitudes in question would not significantly alter projections of food supply (Tubiello et al., 2007). Even if that is true for the large-scale effects, their response rather misses the point in a development context: this is clearly not going to be the case for local-level effects. The AR4 gives figures of 10-25% yield increases under unstressed conditions for C_3 crops, and 0-10% increases for C_4 crops, at 550 ppm atmospheric CO_2 concentrations. These figures are given with only medium confidence, and may need to be revised downwards, apparently.

Many studies show that temperature and rainfall changes in the future will modify, and often limit, the direct CO_2 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 (Rotter 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 (Rotter 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 (APSIM, SUCROS, DSSAT, EPIC, WOFOST, etc). This makes the studying of climate change impacts on food crop growth relatively straightforward (insofar as rainfall, temperature, and CO_2 effects on crop physiology, growth and development are concerned). There is a large literature on possible impacts using different downscaling techniques and emission scenarios, a lot of which is summarised in AR4.

In terms of impacts on grasslands, 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_2 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.

The AR4 indicates that in pastures, elevated CO_2 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_2 levels may favour C3 plants over C4 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). In sown mixed pastures, elevated CO_2 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 1,350 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).

There is some information on the likely impacts of climate change on forage quality, although little seems to be relevant to the tropics. 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_2 concentrations. At the same time, the decline of C4 grasses (which are less nutritious than C3 plants) may compensate for the reduced protein content under elevated CO_2. However, the opposite effect is expected under associated temperature increases (IPCC, 2007).

There seems to be general agreement on two things concerning grazing systems and climate change: grassland and (particularly) animal response is 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 up to 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).

As the AR4 notes, very few impact studies have been done for tropical grasslands and rangelands. Some recent work is highlighting the need for a considerable expansion of effort in this area. Tews et al. (2006) describe some 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 and climate change, Tietjen and Jeltsch (2007) highlight two shortcomings of existing models: being able to model the impacts of increased CO_2 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 decisions 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.

Heat stress

There seems not to have been a great deal of work on the direct impacts of climate change on heat stress in animals. 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.

Some of the literature is summarised by Sirohi and Michaelowa (2007). They cite Hahn (1999) as giving the thermal comfort zone for temperate-region adult cattle as being in the range 5-15 °C, and McDowell (1972) as noting 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. Sirohi and Michaelowa (2007) list several occasions in the last twelve years when heat waves have caused substantial mortality in livestock in the USA and northern Europe.

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). 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, 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., 2005). 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).

Rotter and van de Geijn (1999) suggest that impacts of heat stress may be relatively minor for relatively intensive livestock production systems where some control can be exercised over the exposure of animals to climate. It is certainly the case that 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 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. Over the 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. It is possible that herd sizes may be severely affected in general, if extreme events occur at intervals that are too short to allow numbers to recover, but this is speculation — considerable work is needed in this area.

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 — the MA (2005) indicates that between 1.5 and 3 billion people depend on groundwater for drinking. 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 five-fold 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 3,000 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.

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 per 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 and an ensemble of 12 different 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 EHCam4 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 have not been well-studied. A case-study in a region of Botswana concludes that the key contribution of groundwater to extensive grazing 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. In addition to the impacts on heat stress (see section above), 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 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). For *Bos taurus*, intake at the same three temperatures is about 3, 8 and 14 kg per 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% to 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 livestock systems are fraught with uncertainty, particularly in situations where groundwater accounts for a substantial portion of the supply of water to livestock. 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.

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 and Confalonieri, 2005) – 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 little attention, although there are some exceptions (Cook, 1992; Harvell et al., 1999; Harvell et al., 2002). As Bayliss 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 most of this section is based), Bayliss 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 GHG 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 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. Things such as future patterns of international trade, local animal transportation, and farm size are all 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 extremely complex, and studying them needs to go well beyond any simple assessment of rainfall and temperature effects on distribution — although that is a start. A few examples of this type of analysis have been done. 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 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 Africa, cattle trypanosomiasis, Thornton et al. (2006a) investigated climate-driven changes in habitat suitability for the vector, the tsetse fly. While climate will modify (generally decrease, but not everywhere) 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. This corresponds with the results of a modelling study of changes in malaria distribution in Africa by Hay et al (2006). Their results indicated that climate change is likely to increase the numbers of people at risk of the disease, but that these increases are small when compared with the likely impacts of demographic changes.

More integrated assessments have been attempted, that go beyond the distributional effects of the vector of disease. 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.) AR4 notes that most assessments do not explicitly consider the impacts on livestock health as a function of CO_2 and climate combined. Whether CO_2 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 is also due to the problems noted in section 2.4 above. 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). As noted above, 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 particularly challenging.

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 twentieth century, some 16% had become extinct by 2000, and 12% of what was left was rare. The recent 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). Much of this genetic erosion is attributed to global livestock production practices and the increasing marginalisation of traditional production systems and associated local breeds.

Grim though such figures are, the potential for even more genetic devastation in the future as a result of inexorably rising temperatures is yet greater. 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). The 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_2 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 services. 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.

Despite this, there are several immediate steps that can be taken to improve animal genetic resources characterization, use and conservation. These are summarized by Seré et al. (2007) as follows:

- “Encourage the continuing sustainable use of traditional breeds and in situ conservation by providing market-driven incentives, public policy and other support to enable livestock keepers to maintain genetic diversity in their livestock populations.
- Enable access to and the safe movement of animal genetic resources within and between countries, regions and continents — a key factor in use, development and conservation of animal genetic resources globally.
- Understand the match between livestock populations, breeds and genes with the physical, biological and economic landscape. This ‘landscape livestock genomics’ approach offers the means to predict the genotypes most appropriate to a given environment and, in the longer term, to understand the genetic basis of adaptation of the genotype to the environment.
- New technologies make ex situ, in vitro conservation of animal genetic resources feasible for critical situations and are a way to provide long-term insurance against future shocks.”

In summary, 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., 2007).

Livestock systems

As noted previously, most of the work done on agricultural impacts of climate change has focussed on crops. It is thus not surprising that 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 angle 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 (here, intensification) 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. The effect of population density on crop-livestock interactions can be described by an inverted "U" relationship. At low levels of population density, crop and livestock production systems are extensive and the sole interactions tend to be through markets. As the population grows, systems intensify, both the demand for agricultural products and the opportunity costs of land increase. Intensification tends to occur through increased crop-livestock interactions, as farmers exploit crop residues and manure. At higher population densities and higher levels of intensification, markets develop and on-farm crop-livestock interactions become less attractive, resulting in a return to specialisation and dependence on purchased inputs. This generalised framework is of course 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 counties 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, 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 years — what may be termed 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; as noted above, 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 has not been much work done to try to disentangle the complexity of systems' evolution in relation to climate change — at least, there is not much that could truly be said to be integrative and that includes humans. 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 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 an attempt in a recent paper by Harle et al. (2007) is a welcome exception. These authors 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 to mixed 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).

More recently, some broad-brush vulnerability assessment work (Thornton et al., 2006b) involved expanding the Seré and Steinfeld (1996) livestock systems classification to include other important communities whose livelihoods are not dependent on livestock. An extended systems classification was developed using version 3 of the mapped Seré and Steinfeld classification (Kruska et al. 2003; Kruska 2006) and the FAO farming systems classification outlined in Dixon & Gulliver (2001). This was then overlaid with projected changes in length of growing periods to 2050, to identify those systems most at risk from deleterious climate change. While it is thus possible to identify agricultural systems in Africa most at risk from climate change (the rangeland-based arid-semiarid and mixed rainfed arid-semiarid systems in substantial parts of West, East and southern Africa, for example), more work is needed on seeing how the systems themselves might change in the future. In addition to population and climate changes, some type of simple land-use model would seem to be needed for this.

The Thornton et al. (2006b) vulnerability mapping work also highlighted the need to develop plausible future scenarios of vulnerability changes. 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. Some examples of scenario analysis were given above in section 2.4. The MA scenarios mentioned there, designed to explore contrasting transitions of society as well as contrasting approaches to policies for managing ecosystem services (MA, 2005), have also formed the basis for work designed to investigate the future of the livestock sector in developing countries (ILRI-FAO, 2006).

While the development of plausible scenarios of the future is necessarily qualitative, a lot of work has been done on quantifying some 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. One example is the International Assessment of Agricultural Science and Technology for Development (IAASTD, 2007), an international effort to evaluate 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). A recent paper by Rivington et al. (2007) argues that any effective integrated assessment approach will need to combine simulation modelling with deliberative processes involving all stakeholders — it is hard to argue with that, although the idea of participatory modelling has been around for a while. 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 systems 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 another black hole.

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 and Confalonieri (2005) 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., 2005), and these may be considerable.

While climate change impacts may have few direct effects on other important 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). 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).

4 Responses to climate change

The usual approach to considering what actions might be taken in response to climate change is to break the problem up into two: what might people do to cope with the impacts of climate change, given that they are going to occur — adaptation; and what actions might people take to lessen the impacts of human activity on the climate system — mitigation. This is how the AR4 is arranged, for example; Working Groups 1, 2 and 3 consider issues relating to the changing climate, adaptation issues, and mitigation issues, respectively. Mitigation and adaptation can really be seen as two sides of the same coin. If, for example, the European Union target of stabilising climate temperature increases to 2 °C above pre-industrial levels is to be met, then with a probability of at least 50% this may require stabilisation of the CO2 concentration below 450 ppm. This is certainly possible, and the Stern review concludes that this is an economically attractive goal (Stern, 2006). The Stern review has been dismissed as "alarmist and incompetent" in some quarters (e.g. Tol, 2006) and given very strong support in others (e.g. DFID and the UK Government), but there is widespread agreement that for this EU target to be met, stringent climate policies would need to be implemented and emissions cut. It has been argued by some that a 2 °C increase is too much anyway, that we do not understand what the full impacts of this rise may be, and that we should be aiming at a much lower target.

At the same time, whatever targets are aimed for via mitigation policy and action, there are considerable lags in the earth system, and climate change impacts are inevitable in the coming decades, even if all GHG emissions were cut tomorrow. Particularly for vulnerable people, this means that adaptation options will be needed if households are to cope with the changes brought about. There is not a simple polarity between adaptation and mitigation, however, either in terms of classifying actions as one or the other, or in terms of where mitigation ("in the North, where most of the GHG emissions emanate from") and adaptation ("in the South, where most of the poor and vulnerable people are") should be carried out. There are various options in relation to livestock systems that may be viable in many situations for pastoralists and smallholders in the tropics, that can reduce the negative impacts of livestock on climate (mitigation) while at the same time increasing household food security and/or income and reducing vulnerability (adaptation).

The purpose of this section is not to summarise the enormous and ever-expanding literature on adaptation and mitigation, but rather to highlight a few issues of particular relevance to livestock and development.

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 very large variety of possible adaptive responses available. These range from technological options (such as more drought-tolerant crops), through behavioural (such as changes in dietary choice) and managerial (such as different farm management practices), to policy (such as planning regulations and infrastructural development). The range of adaptation options to climate change has been summarised in several places, including in Kurukulasuriya and Rosenthal (2003), who define a typology of adaptation options that includes the following:

1 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.

2 Income-related responses that are potentially effective adaptation measures to climate change, such as crop and flood insurance schemes, credit schemes, and income diversification opportunities.

3 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.

4 Technological developments, such as the development and promotion of new crop varieties, improvements in water and soil management, and improved animal health technology, for example.

Kurukulasuriya and Rosenthal (2003) discuss options under these four headings, in terms of whether they are appropriate for the short term or the long term (or either). As they (and many others) have pointed out, there are many factors that will determine whether specific adaptation options are appropriate and viable in particular locations.

The short- and long-term distinction in relation to adaptation is important, as two separate but related approaches are commonly pursued. In the short-term, there seems to be a growing consensus that 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, specifically) 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 notion stems from two key constraints that pervade Africa — 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 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 a very 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. 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 (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 profound 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".

In any case, the "climate change as a risk management issue" approach is in the process of being institutionalised in many organisations, including the World Bank (van Aalst, 2006). There is already a very large literature on the uses of climate information for adaptation, and these uses have been categorised by Smit et al. (2000) — Table 6 shows the categories, taken from Wilby (2007). As Wilby (2007) notes, such activities are not mutually exclusive; some are better placed than others to meet the specific needs of different adaptation assessments; and there are large disparities between techniques in terms of their respective technical capacity and resource requirements.

There are several studies that demonstrate the utility of climate risk management approaches for adaptation in the water, health and agricultural sectors. In the African context, there are still severe challenges to be overcome, 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). In general, however, there are some issues related to the effectiveness of climate forecasts for crop and livestock management in an African context that need to be addressed.

Not all adaptation issues are most appropriately seen in a risk management light, of course. Approaches to longer-term adaptation are often couched in terms of "climate-proofing development" or something similar. A little reflection shows that practically all research for development activity has to take climate change into account, in one way or another - it pervades everything. The lag times between problem identification and ready, appropriate

How can livestock keepers respond? Box 1

Example 1. Croppers and livestock keepers in Mali using weather information

"Agriculture in Mali is a high-risk venture -- about 65% of Mali's land area is either desert or semi-desert, and less than 4% is used to grow crops -- but rainfed agriculture is the mainstay of most rural peoples' livelihoods. Recognizing that rural communities need help in managing the risks associated with rainfall variability, Mali's Direction Nationale de la Météorologie, the national meteorological service, launched a project some 25 years ago with external funding, to provide climate information to rural people. The project has evolved into an extensive and effective collaboration between government agencies, research institutions, media, extension services, and farmers. This was the first project in Africa to supply climate-related advice and recommendations directly to farmers, and to help them to measure climate variables themselves, so that they could incorporate climate information into their decision making.

Among other products, ten-day bulletins are produced by multidisciplinary working groups, which provide the basis for information and advice to farmers as well as to national policy makers on the food security status of the country. Bulletins are disseminated by radio and television, as well as in printed versions. They report on the state of crops, water resources, and weather conditions, as well as crop health issues, pastoral issues, animal husbandry, and agricultural markets. They also predict future conditions.

Evidence from the project suggests that when farmers have good climate information, they are able to make better management decisions that lead to higher yields and incomes. They may also be prepared to take more risks and invest in new technologies, and they start to seek information from other sources to improve their decision making."

From Hellmuth et al. (2007)

Table 6. Examples of adaptation activities that require climate risk information (Wilby (2007), from Smit et al. (2000))

Adaptation	Examples of activity using climate information
Technological	Cost-benefit analysis, infrastructure performance and design
Appraisal	Assessment of natural resource availability, status, allocation
Adjustment	Scoping assessments to identify risks and reduce exposure to extreme events
Behavioural	Measures that optimise scheduling or management
Institutional	Economic planning, sector restructuring, guidance, standards
Information	Communicating risks to stakeholders, high-level advocacy
Financial	Services to transfer risk, incentives, insurance

technology is often very long. Jones et al. (2008) note that the entire process for "green revolution rice", the variety IR8, lasted some 36 years, from finding the useful genetic trait (short-statured rice), creating the new variety, testing and disseminating it, and the "natural" lifespan of the variety so developed (which is not infinite: it has been estimated that if IR8 were planted today in the same fields across South and South-east Asia, regional yields would fall by 20%, not because of changes in IR8 but because of changes in the environment, particularly soil and water — see http://www.irri.org/publications/annual/pdfs/ ar2000/IR8.pdf). This is not atypical: the first generation of drought-tolerant beans in Latin America is only now reaching the release phase, and that has taken 30 years so far (Jones et al., 2008). The research on fodder banks of Stylosanthes as a dry-season feed supplement for livestock in West Africa started in 1975 and was quite quickly completed, but adoption in some countries is still continuing (a lag of 30 years and counting, Elbasha et al., 1999).

It is totally obvious that much of the research that is being carried out today in the CGIAR centres and elsewhere, if it ever gets applied in farmers' fields, will need to be appropriate to the environment of 30-50 years' time, not to the environment of today. This has all sorts of implications for targeting as well as research design, testing and implementation. Research outputs clearly have to be thought out in relation to how the climate is changing in the target domain. We are starting to have tools available that can help in this. An example is looking for homologues of future climates that exist now. If, for example, a researcher is looking for new forage germplasm for specific sites in a particular domain, it is necessary to find out what the climate is likely to be at those specific sites in 20-50 years' time. Testing of promising new lines now might then take place at different sites that exhibit the key characteristics of the domain climate in the future — assuming that such homologues can be found.

Practically all of the longer-term research activities that ILRI is (or may become) involved with need to be viewed from this perspective. Climate change in Kenya, for example, 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. It is fairly certain that the suitability of many of Kenya's tea-growing areas is going to decrease considerably in the future. There are clear market issues involved here. 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 are going to have an impact on water availability for cattle, with concomitant impacts on grazing orbits and the ecology of grasslands that may greatly threaten the sustainability of these systems.

It is interesting to consider how research allocation decisions in the past might have changed, had climate change been taken into account. Trypanosomiasis research is an interesting case in point. Given that the habitat of the tsetse fly by 2050 will have undergone very extensive contraction because of remorseless population growth and climate change impacts (we know much more of the details of both of these factors now than we did 25 years ago), an ex-ante impact assessment of a trypanosomiasis vaccine done in 1980 compared with one done know would look very different, all other things being equal. (In fact, this would be an extremely interesting analysis to carry out, and even a relatively quick-and-dirty study could provide some quantitative evidence as to the potential dangers of omitting climate change from ex-ante impact assessments.)

Perhaps a key point is that, in a real sense, the issues associated with adaptation options involving livestock are no different from those of "normal" research for development, whether in a risk management framework or in a climate-proofing framework. Decisions still have to be made concerning where to target activities, which options to assess, test and implement, how to identify the appropriate entry points into the systems, etc. This suggests several possible activities:

1. 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.

2. There is considerable work needed on frameworks for impact assessment (in the broadest sense of the term) — this has been noted in successive IPCC Assessment Reports. From a livestock for development perspective, there are perhaps two key issues here. One is, that frameworks need to be expanded to be able to say something about the costs and benefits of different adaptation options. It is not only that policy makers have limited resources with which to address the many and sometimes conflicting objectives that make up government policy aims, but also the recognition that policy makers may only have limited leeway in terms of what can be undertaken. Second, impact assessment frameworks need to be coherent, comprehensive, and comparable with similar efforts in other sectors. The disaster management sector, for example, has many of the same aims as the development community, but tools, databases, methods, frameworks etc are often developed in each sector in ignorance of what is going on in the other.

3. There are critical issues related to stakeholder involvement, information demand and supply, and getting research outputs into use. In essence, adaptation to climate change requires that

How can livestock keepers respond? **Box 2**

Example 2. Livestock insurance schemes

"Climate change has given an impetus to a range of initiatives aimed at extending access to micro-insurance and weather derivatives in the developing world. One problem with such schemes is that traditional crop insurance can create perverse incentives, including the incentive to let crops fail during periods of low prices. Weather-indexing can address this problem. In India, the Comprehensive Crop Insurance Scheme insures farmers who use official credit systems, charging a small premium and using weather-indexes (rather than farm production) to determine claims. Premium holders are paid in response to 'trigger events' such as delayed monsoons or abnormal rainfall.

Another problem is developing schemes that are accessible to the poor. The participation of smallholder farmers' groups in the design of insurance packages and the provision of collateral through 'social capital' have produced some promising results."

There is promise for schemes for livestock as well as for crops, such as a programme for offering insurance to herders in Mongolia to compensate for animal deaths during severe winters. This is looking at the potential for using the livestock mortality rate at a local level as the basis for indemnifying herders ("Examining the feasibility of livestock insurance in Mongolia", by Enkh-Amgalan & Skees, Policy Research Working Papers, World Bank, 2002).

"There is undoubtedly scope for enhanced insurance coverage using weather-indexing, but there are probably limits to what private insurance markets can achieve for large vulnerable populations facing covariate risks linked to climate change."

From UNDP (2008)

multiple stakeholders, including the research for development community, change or modify their behaviour. It is not possible for research to contribute to improving 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 is always constrained by the institutional, social, economic and political environment in which people must operate. There is a great 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.

4.2 Mitigation

The AR4 states that both bottom-up (specific mitigation options) and top-down (economy-wide) studies indicate that there is substantial economic potential for the mitigation of global GHG 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 (the AR4 considers energy, transport, buildings, industry, agriculture, forestry/forests, and waste). There is "medium" agreement that agricultural practices collectively can 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 short term (in the AR4, this refers to the period out to 2030), various technologies are listed as being currently available and promising for their mitigation potential:

- Improved crop and grazing land management to increase soil carbon storage;

- Restoration of cultivated peaty soils and degraded lands;
- Improved rice cultivation techniques and livestock and manure management to reduce methane emissions;
- Improved nitrogen fertilizer application techniques to reduce nitrous oxide emissions;
- Dedicated energy crops to replace fossil fuel use; and
- Improved energy efficiency in general.

By 2030, improvements in crop yields are also envisaged to have played a role in reducing GHG emissions directly and indirectly.

The total macro-economic costs in 2030 of a stabilised CO2 concentration of between 445-535 ppm CO2-eq is put at less than 3% of GDP. This is equivalent to a global mean temperature increase at equilibrium of 2.0 to 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 CO2-eq, carbon prices would need to be of the order of US$ 20-80 per tonne CO2-eq by 2030 — at which prices large shifts of investments into low carbon technologies could be anticipated (IPCC, 2007).

There are many technological options that already exist that can mitigate GHG emissions from agriculture in general and from the livestock sector in particular. Many of these are discussed in Steinfeld et al. (2006) in relation to GHG emissions, water issues and biodiversity. The livestock mitigation debate is in fact evolving very rapidly in the developed countries. When a journal as

How can livestock keepers respond? **Box 3**

Example 3. Change the mix of livestock species

"One long-term recovery strategy and insurance against the impact of future droughts is changing the species in the herd. Although cattle are prestigious and highly valued in the market, they are vulnerable to drought in comparison to camels and goats. The relatively high rainfall in the 1960s encouraged pastoralists all across the Sahel to switch from camels to cattle, even populations such as the Tuareg in Mali who have been historically identified with camel-culture. The droughts of the 1970s demonstrated that this was an unwise strategy and their recurrence in the 1980s underlined this point."

In another example, "... the Samburu of northern Kenya have a long and close association with several camel-keeping neighbours, yet only relatively recently have they begun to adopt camels for use in their own home settlements. This spread seems to be related to a long cycle of decline in their cattle economy: since 1960, droughts, raiding, and several epizootics have substantially reduced their aggregate cattle holdings" (L Sperling, "The Adoption of Camels by Samburu Cattle Herders", Nomadic Peoples 23, 1-18, 1987).

"These types of changes in herd composition can also apply within species. In West Africa, cattle breeds that specialise in grass are more prestigious than those that can digest a high proportion of browse. However, where low rainfall or high grazing pressure has changed the species composition of the landscape so as to favour shrubby vegetation, the herder with cattle that can tolerate a higher proportion of browse in their diet will survive better. FulBe herders in Nigeria, faced with rapidly vanishing grass in the semi-arid zone, have switched their herds from the Bunaji breed, which depends on grass, to the Sokoto Gudali, which can digest browse much more easily."

From R Blench and Z Marriage, "Drought and livestock in semi-arid Africa and southwest Asia". Working Paper 117, Overseas Development Institute, London, March 1999 august as The Lancet carries an article that urges a reduction in livestock product consumption globally, as a (presumably) serious contribution to the GHG mitigation and health debate (McMichael et al., 2007), this is as clear a wake-up call for the "livestock in development" community as there could possibly be.

It may be a bit fanciful to envision emission-free ruminants roaming the hinterland of the Masai Mara (and in any case, modification of the microflora of the rumen inevitably reduces its efficiency in some way) — but what of mitigation options in livestock-based systems in developing countries that can contribute to livelihoods and incomes?

Reid et al. (2004) review mitigation options in the pastoral lands 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 CO2, 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). Whether such conversions are likely in specific situations is, of course, another question.

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 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 some formidable 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, for example, the mitigation story is basically likely to be the same. Technical options do exist — for example, some recent work indicates that modest changes to the crop-livestock systems in Ghana can have positive impacts on carbon sequestering (Gonzalez-Estrada et al., 2008) — but these are subject to similar institutional and implementational issues as for the pastoral systems.

In a development context, a pragmatic approach will involve looking at mitigation options using an analytical framework that can examine the trade-offs involved. The trade-offs may be geographically very far-flung: there is a substantial "North-South divide" in terms of GHG emissions. Globally, there is a huge imbalance between the emissions that emanate from the North and those that come from the South — the 19 million people living in New York State have a higher carbon footprint than the 146 Mt CO2 left by the 766 million people living in the 50 least developed countries, according to the Human Development Report (UNDP, 2008). But many of the deleterious impacts of these emissions will eventually be felt in the South, not the North. The whole notion of "action at a great distance" is very well pointed up by the biofuels issue. There may be income-generating opportunities for smallholders associated with biofuels, although there are issues with the energy efficiency of current technology. The biofuels sector is one of the most highly dynamic and rapidly changing sectors of the African energy economy (see, for example, http://www.africa-union.org/root/ua/Conferences/2007/juillet/IE/30% 20juillet/Biocarburants_Eng.htm). While biofuels have the potential to provide much-needed energy for industrialisation and export, however, there are growing concerns that biofuels development could have enormous impacts on water pollution, deforestation, and food security through competition for land, water and labour. It is clear that the potential opportunities for biofuel development that may increase incomes for smallholders will have to be carefully screened and the trade-offs assessed. This seems to point in the same direction as for adaptation options — the development and application of appropriate impact assessment frameworks that can be used for such analyses would be an area where progress needs to be made.

5 Where are the Gaps and Opportunities?

In this section, an attempt is made to identify some candidate areas of research that ILRI might get involved in, that would probably warrant further thought (and possibly analysis). There would seem to be three elements to this, and the structure of this section follows this breakdown:

- First, from the preceding sections of the paper, some gaps can be identified in general areas, and these are qualitatively scored as to their relevance to ILRI's mandate and mission.
- Second, ILRI's latest Medium-Term Plan can be used to identify areas in the research portfolio over the next 3-5 years where climate change research might be beneficial or where climate change information might be particularly useful.
- Third, some broad trends can be identified that may have a substantial impact on forming public opinion in the North and hence on public funding of research on development issues in the South.

Taking these pieces together, a breakdown is then attempted by region and topic area, and some criteria are presented by which the candidate activities are quickly and qualitatively assessed.

Before starting on these three elements, there are several key things that are worth keeping in mind. First, it needs to be remembered that the primacy of the outputs shown in Figure 1 is absolute: reduced poverty, increased food security, and reduced negative feedbacks to the earth system. There are considerable differences in the socio-economic and cultural roles of livestock between developed and developing countries, and even between developing countries in different regions. There are several implications of these differences, not least the fact that ILRI and other organisations concerned with poverty reduction and livestock issues may be ploughing a lone furrow, in relation to conventional (but often wrong) wisdom in parts of the world where poverty and livestock are not intimately entwined (more on this below). Socio-economic and cultural differences also give rise to very different types of problems; in general, more developed countries may need to work on mitigation options, while it may be more appropriate for certain developing countries to concentrate on adaptation issues, for example.

Second, not much work seems to have been done on this, but it is highly unlikely that the multiple impacts of climate change will be either continuous or linear. As with complex systems in general, non-linearity of responses and system discontinuities are likely to be the norm. The notion of tipping points in climate change response in producing major social upheaval in the US is rather alarmingly discussed in Gilman et al. (2007), but the points made concerning discontinuities are important and need to be borne in mind in relation to agro-ecosystems and livelihood systems. On a much more minor scale, the crop simulation results discussed in Thornton et al. (2008) for parts of East Africa highlight the kind of nonlinearities in response that can be expected (if not the discontinuities — for which we will need substantial input into developing and using integrated biophysical-human models). This also highlights the fact that impact assessment and adaptation are continuous processes, not one-off activities.

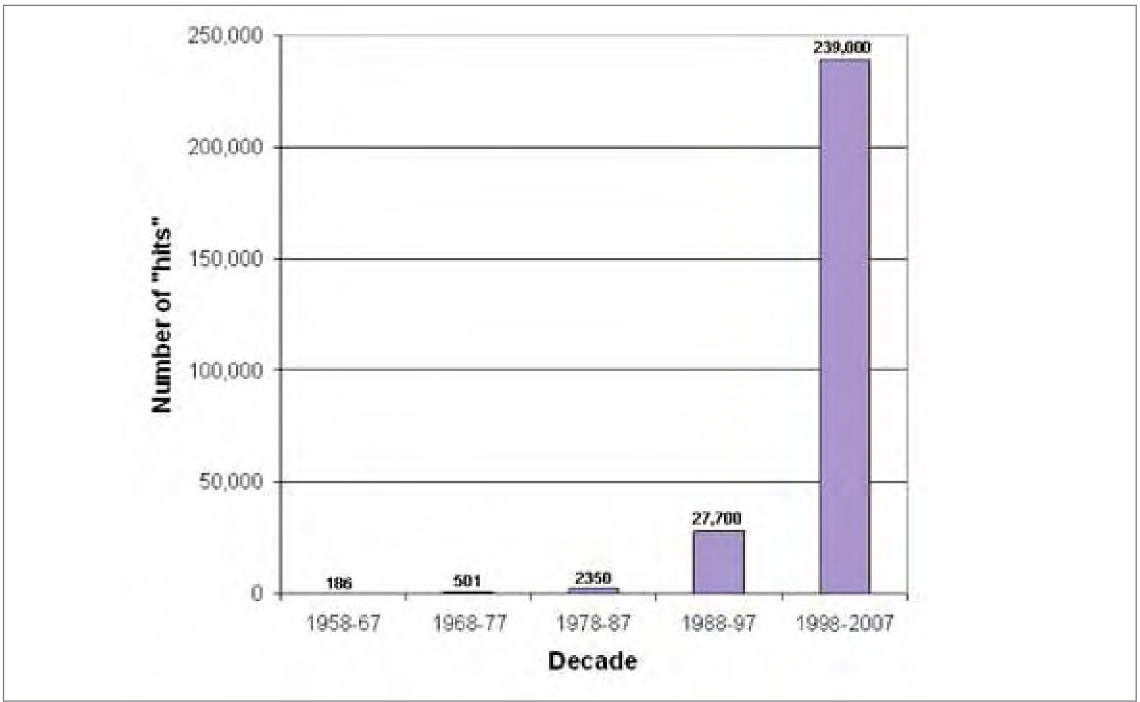
Third, it is quite clear that ILRI, and indeed the CGIAR as a whole, is but a small player in an already-crowded field of climate change research. The literature on environmental and climate change issues is expanding exponentially. Figure 8 shows the results of a simple literature search using the term "climate change" over the last 50 years. In addition, the last two years have seen the completion and publication of at least five major reviews — MA (2005), GEO4 (2007) , IAASTD (2007), IPCC (2007), Comprehensive Assessment (2007) — involving hundreds of scientists and scientist-years and producing many thousands of pages of output. There are very many organisations and people working on these issues, and it is therefore critical that a niche is identified for ILRI activities that is both strategic and relevant to the broader development agenda.

Despite the feverish activity going on globally in the area of climate change, it is apparent even from the very brief and rather discursive overview presented in sections 3 and 4 above that there are some key knowledge gaps in relation to climate change, its impacts on livestock and livelihood systems, and its broader implications for development and poverty alleviation. Table 7 attempts to tabulate some of these, in relation to specific areas. The first six areas correspond to the subheadings of section 3 above, and three other areas are included: impact assessment, adaptation, and mitigation. Each gap identified is then rated low, medium or high in relation to its relevance to ILRI in achieving the three key outputs shown in Figure 1: poverty alleviation, increasing food security, and decreasing the negative feedbacks to the earth system (or more generally, improved environmental benefits). Thus if a gap is scored "low", this does not mean that there is no clear link to the output shown; it simply means that even if it is important, it is not of direct relevance to ILRI and ILRI's activities. A good example is the question, How do human health impacts intertwine with livelihood systems and vulnerability? There is little doubt that this is extremely important, and that there are critical inter-relationships here, but in terms of ILRI's current and possible future research portfolio, there is probably little that ILRI will do directly on this issue, so it is scored "low" in Table 7. There are a couple of other things to note about the table. One is, that it includes only gaps that have a reasonable chance of being filled. For example, in the area of livestock disease, an undoubted gap is "the nature of the changing probabilities of epizootic disease outbreaks of economic importance" — but in the foreseeable future, there are only limited prospects for being able to quantify what these probability changes may be, in relation to changing climate. Another point is that the table hides regional variation — the mitigation gaps may be much more important in the industrial livestock systems of south-east Asia than in sub-Saharan Africa, for example. An attempt is made below to deal with regional variation.

For the second element, a brief look at ILRI's current activities is useful. Table 8 brings together the high-level outputs of the four ILRI Themes, taken from the MTP for 2008-2010. The third column in Table 8 indicates the overall relevance of climate change issues to each output (low, medium and high). While it is clear that climate change issues could be important for all outputs particularly over the longer term, there are some where the relevance is perhaps much more immediate than in others.

There are already several activities going on at ILRI on climate change research. Some detail on specific activities (both completed and being undertaken) is shown in Appendix 1, in which research projects are listed under three research areas: targeting and system change, animal health and genetic resources, and land use and natural resources. There is already something of an evolving agenda in relation to some of these activities. For example, recent work on identifying hotspots of vulnerability to climate change in Sub-Saharan Africa confirms that arid and semi-arid areas are amongst the most vulnerable agro-ecosystems to adverse impacts of

Figure 8. Number of documents returned in Google Scholar on 30 January 2008 using the search term "Climate change" for the five decades since 1958.



climate change. These areas include pastoral, agro-pastoral, and mixed cropping systems where large numbers of households depend on livestock for their livelihoods. This system dimension and the livelihood implications for livestock keepers, poor people, and their communities, can certainly provide one strategic entry point for ILRI's climate change research agenda. This broad-brush work is already being followed up in several ways:

- Medium-resolution (country and system) vulnerability and impact assessment studies, to generate knowledge on the impacts of climate change on livestock-based livelihood systems and provide insights into the broader issues of poverty reduction and sustainable development in identified hotspots. Such work can be a key input to the design and planning of research activities both for ILRI and for a range of organisations such as donors and development partners.

- Household-level analysis to assess climate impacts on food security, livelihoods, and household trade-offs, and to explore feasible options for reducing vulnerability and increase capacity to adapt to adverse effects of climate change.

The third element that should be taken into account involves some crystal ball gazing, in terms of attempting to determine some of the key trends that may affect public perception and behaviour, and hence the donor climate. Perhaps a more proactive way of looking at this is rather to try to identify where and how might ILRI provide knowledge that can inform the debate and actually influence public perception in a positive way. There are at least two on-going debates in which ILRI could contribute balance in a substantive way. One of these was referred to in section 4.2., and can be summed as the "livestock are bad everywhere" perception (the

Table 7. An attempt to summarise key, general knowledge gaps of climate change impacts on livestock-based livelihoods and their relevance to attaining the key outputs of Figure 1 (poverty reduction, increased food security, and reduced negative feedbacks to the earth system), from an ILRI-centric perspective

Area	Gaps	Relevance via an ILRI pathway to		
		Reducing poverty	**Increasing food security**	**Improving environmental benefits**
Feeds: quantity & quality	What are the localised impacts?	High	High	Low
	Rangelands: primary productivity impacts species distribution and change due to CO_2 and other competitive factors, estimation of carrying capacities.	Medium	Medium	Low
	Crops: primary productivity, harvest indexes and stover production, dual purpose crops, higher quality stovers.	Medium	Medium	Low
	New feeding strategies due to changes in diet components & quality	Medium	Medium	Medium
	Management of new feeds, production and storage.	Low	Medium	Low
	Feed market changes in response to supply and demand changes.	Medium	Medium	Low
	Impacts of pests and diseases of key grasses and cereals (e.g. Napier smut in the Kenyan highlands)	Low	Medium	Low
Heat stress	Do we know if it is going to be important, even?	Low	Low	Low
Water	Surface and groundwater supply, and impacts on livestock	Low	Medium	Medium
	Increases in livestock water productivity	Low	Medium	Low
Diseases and disease vectors	How may the prevalence and intensity of key epizootic livestock diseases change in the future?	Low	Medium	Low
	In wetter areas, what may the impacts be of more "management" diseases such as mastitis?	Medium	Low	Low

		(Reducing poverty)	(Increasing food security)	(Improving environmental benefits)
Biodiversity	'Ecological biodiversity': what will happen to numbers of species as systems change?	Low	Low	Medium
	Animal breed biodiversity: is it possible to specify the animal genetic resources that might be useful in the future?	Medium	Medium	Medium
	Plant biodiversity: should we conserve germplasm that might be useful as feeds in the future?	Medium	Medium	Medium
Livestock systems	Impacts on livelihoods	High	High	Medium
	Magnitude and effects of systems changes (land use, degradation, soil fertility, etc)	Medium	Medium	High
	Impacts on ecosystems goods and services	Medium	Medium	High
Indirect impacts	How do human health impacts intertwine with livelihood systems and vulnerability?	Low	Medium	Low
Impact assessment and trade-off analyses	Assessment frameworks and targeting tools	High	High	High
Adaptation	Which options, and where are they applicable / viable (toolboxes)	Medium	High	Medium
Adaptation	Information supply and demand ("Research into use")	Low	Low	Low
Adaptation	Under what conditions will specific livestock-related risk management options work?	Medium	Medium	Medium
Mitigation	Assessment of biofuels - where and how can they contribute to poverty alleviation in livestock systems?	Medium	Low	Medium - High
	What are the key trade-offs in biofuels versus feed versus conservation agriculture/ soil fertility management?	Medium	Medium	Medium
Mitigation	Carbon sequestration - where and how can this contribute to poverty alleviation in livestock systems?	Low	Low	Low
Mitigation	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)?	Low	Low	Medium

Table 8. Outputs at the theme level, from the ILRI MTP 2008-2010

ILRI Theme	Outputs	Immediacy of CC inputs
Targeting and Innovation	T1 Understanding of trends and alternative futures of livestock sector development used to set priorities and influence resource allocation decisions that enhance the prospects for using livestock as an instrument for reducing poverty in the developing world (3-5 years).	High
	T2 Improved and better targeted policies and strategies identified to guide design and formulation of sustainable pro-poor livestock interventions and poverty reduction (3-5 years).	Medium
	T3 Analytical framework and tools for identifying and assessing impacts for livestock based interventions developed and used for targeting pro-poor investment choices (3-5 years).	High
	T4 Enhanced understanding of process and mechanisms that enable the use of research outputs into innovations for sustainable improvement in the well being of poor people who depend on livestock for livelihoods (5-10 years).	Low
Market Opportunities	M1 Technical, institutional and policy options identified and promoted, that increase the ability of smallholder livestock producers to sustain and expand viable livestock enterprises (3-5 years).	Low
	M2 Technical, organizational and policy options identified and promoted for improved market institutions that serve small-scale, poor and disadvantaged producers, market actors and consumers, in the context of rising demand for reliable quality, food safety and increased openness to trade (3-5 years).	Low
	M3 Strategies and policies identified and promoted for greater impact on poverty reduction through improved quality and safety of livestock commodities and products in national and international markets, through multi-disciplinary research in veterinary epidemiology, economics, and risk analysis (3-5 years).	Low
Biotechnology	B1 New/improved vaccines and diagnostics (Africa and Asia, 3-5 years).	Medium
	B2 Phenotypic, neutral and functional genetic molecular diversity of AnGR characterized, quantified and mapped to inform livestock conservation and utilisation strategies (Global, 5-10 years).	Medium
	B3 Livestock breeding and conservation programmes suitable for low-input systems established to enhance productivity and adaptation. (Sub Saharan Africa, South Asia and South East Asia, 3-5 years).	Medium
People, Live-stock & the Environment	P1 Institutional, management, policy and technical options to enhance environmentally sustainable livestock-based livelihoods through more effective, efficient and equitable use of water resources available for SSA and South Asia.	Medium
	P2* Viable and sustainable livestock-related options (policies, strategies, practices, institutions) to improve environmental sustainability and reduce human vulnerability to zoonoses in pastoral and agropastoral systems available in sub-Saharan Africa and Asia.	Low
	P3 Approaches defined for balancing improved feeding and productivity with optimal resource use in intensifying crop-livestock systems in SSA and S.Asia.	Medium
	P4 Knowledge and germplasm for forage resources available as part of a rational global system of genetic resources conservation and sustainable use.	Low

The Systemwide Livestock Programme is not included here explicitly. However, position papers are being developed (during 2008) on (1) the drivers of change in crop-livestock systems and (2) biofuels and the trade-offs between food, feed and energy, and both of these will be taking account of climate change impacts.

** Since the publication of the ILRI MTP 2008-2010, Operating Project P2 has been moved to the Market Opportunities Theme* mutation of Orwell's Animal Farm dictum into "two legs bad, four legs worse" is almost beyond irony). The reality is, of course, far more complicated; not all livestock systems are equal, and in many developing countries, livestock have multiple roles in poverty alleviation and food security. ILRI could play (and perhaps ought to play) a significant role in assembling information that rigorously demonstrates the critical poverty benefits of livestock in many countries and in general trying to restore some sanity to this debate.

Another on-going debate is that on biofuels. There may be income-generating opportunities for smallholders from biofuels, but as noted above, there are clear trade-offs that have to be assessed in terms of competition for land, resources, and labour. In any case, there are clear limits to the oil substitution that biofuels may be able to provide, and they certainly do not provide any kind of excuse for conspicuous resource consumers and CO2 emitters in the North to banish guilt and take no action on GHG mitigation. If CO2 concentrations are to be stabilised any time close to 2015, then behavioural consumption patters shifts in the North are going to be needed just as much as technological shifts. Again, in this debate ILRI can play a key role in providing information about the reality of the biofuels situation and its implications for the food security of vulnerable people in particular places (see footnote to Table 8 concerning the SLP discussion paper on biofuels). Given the imperfections of markets and distribution systems, there are potentially highly negative implications for poor people through land competition for biofuel production. Biofuels are clearly no solution to any problem if the food security of the resource-poor is reduced or compromised.

Table 9 is an attempt to lay out a set of candidate activities and to describe them very qualitatively in terms of various characteristics and a few criteria on which they could be judged as to their suitability as "ILRI activities". The candidates are an amalgamation of activities in Table 7 with a "medium" or "high" relevance score, Theme outputs from Table 8 with a "medium" or "high" immediacy score, and the trends identified above. For each activity area, the following are included:

- The major research outputs that might come from the activity area.
- The geographic focus of the work, in terms of specific regions of Africa and Asia; some activities are global in scope.
- The systems focus of the work, in relation to the system codes shown in Table 10, which is a version of the Seré and Steinfeld (1996) classification scheme expanded with systems from Dixon and Gulliver (2001), adapted from Thornton et al. (2006b).
- Time to the production of outputs, classed as short (1 year), medium (2-5 years) or long (> 5years).
- Order-of-magnitude cost of the activity, classed as low (USD 10,000), medium (USD 100,000) or high (USD 1M).
- ILRI's role in the activity, classed as leader, contributor, backstopper, or facilitator.
- The Themes within ILRI that would be involved in the activity, as well as the SLP.
- Alternative suppliers of the outputs, if they exist.
- Partners ILRI would need to produce the outputs.

- The general "achievability" of, and a sense of the overall magnitude of the benefits arising from, the outputs, in relation to the current state of knowledge in the field, whether there is research momentum in the needed disciplines, do the required research tools already exist to support the research, and the probability of success in achieving the major outputs. This is classed as low, medium or high.
- Feasibility of delivery: the ease with which the major outputs can be turned into outcomes for end-users, and the plausibility of the pathways required. This is classed as low, medium or high.

In Table 9, there are six entries related to feeds, two each to water, diseases and biodiversity, three to livestock systems (including one, number 15, on case studies of livestock's role in poverty alleviation, adaptation and vulnerability reduction), one on indirect impacts, one on impact assessment frameworks, and two each on adaptation and mitigation per se.

Several things are apparent from Table 9. First, it is clear that many of the activities that may be undertaken at ILRI in relation to climate change are basically to do with bringing a "climate change" perspective to ex ante work, and guiding much longer-term characterisation work on such things as livestock biodiversity, for example. In fact, this is probably the key point — the importance of assessing current and future activities at ILRI through a climate change lens, in much the same way as we now use the different lenses associated with natural resource and gender perspectives, for instance.

Second, there are relatively few activities that are likely to produce outputs in the short term — feed hotspots (activity 1 in Table 9), case studies on livestock's role in adaptation and reducing poverty and vulnerability (activity 15), and some work on livestock-specific risk management adaptation options (activity 19) that could be readily implemented (livestock insurance is one example that comes to mind).

Third, there are relatively few activities in which it would seem to make much sense for ILRI to play the leadership role: again, feed hotspots (activity 1), animal breed characterisation for future exploitation as an adaptation tool (activity 12), identifying impacts on livestock systems and livestock-keeper livelihoods (activity 13), and case studies on livestock's role in adaptation and reducing poverty and vulnerability (activity 15).

There are various ways to analyse the information in Table 9. We decided to rank the activities in relation to three indicators:

- Importance to ILRI, in terms of the relevance of the research outputs to the pathways out of poverty. This is essentially the information in Table 6 reduced to a score from 1 (not so relevant) to 5 (highly relevant).
- ILRI's role and other providers; here we scored 3 for a leadership role, 2 for a contributing role, and 1 for backstopping and facilitating. For other providers, we scored a 3 if there are no other providers, 2 if there are some, and 1 if there are relatively many (e.g. NARS). These two numbers were then added together (i.e., in effect, these two different indicators are given equal weight in the overall score).
- Achievability of outputs (from Table 9 — score 1 for low through to 5 for high) added to feasibility of delivery (score 1 for low through to 5 for high).

Table 9. Descriptive characteristics and assessed criteria for some candidate ILRI research activities in the climate change arena

	Activity Area	Research Outputs	Geographic Focus	System Focus	Time to Outputs	Order-of-Magnitude Cost	ILRI's Role	ILRI Themes involved	Alternative Suppliers of Outputs	Type of Partners Needed	Achievability of Outputs	Feasibility of Delivery (Outputs to Outcomes)
1	Feeds	Localised impacts & hotspots identified	E W S Africa	MRA LRA	Short	Low	Leader	T P S	None?	Other CGs GCC OIOs	High	High (e.g. for priority setting)
2	Feeds	Rangeland NPP distribution & impacts elucidated	E S Africa NE Asia	LRA/H/T	Medium	Medium	Contributor/ Leader	T P	ARIs	ARIs	Medium-High	Medium
3	Feeds	Modified crop & residue quality & quantity	E W S Africa S Asia	MRA/H/T	Long	Medium-High	Contributor	P S	None?	Other CGs	Medium	Low-Medium
4	Feeds	New feeding strategies developed	E W S Africa S Asia	MRA/H/T	Medium-Long	Medium	Backstopper Facilitator	P S	NARS	NARS	Medium	Low-Medium
5	Feeds	New options developed for management, production, & storage of feeds	E W S Africa S Asia	MRA/H/T	Medium-Long	Medium	Backstopper Facilitator	P S	NARS	NARS	Medium	Low-Medium
6	Feeds	Feed markets developed in response to supply/demand shifts	E W Africa S Asia	MRH/T	Medium	Medium	Contributor	M P S	NGOs?	NARS	Medium	Medium
7	Feeds	Hotspots identified of key pests, diseases of key feed crops	E W S Africa S Asia	MRA/H/T	Medium	Medium	Contributor	T P S	OIOs	ARIs NARS	Low-Medium	Medium
8	Water	Understanding of changes in surface and groundwater supply, and impacts on livestock	E S Africa E S W Africa S Asia	LRA/H/T MRA/H/T	Medium	Medium	Contributor/ Leader	T P	OIOs	Other CGs ARIs OIOs	Low-Medium	Medium

Table 9. continued

	Activity Area	Research Outputs	Geographic Focus	System Focus	Time to Outputs	Order-of-Magnitude Cost	ILRI's Role	ILRI Themes involved	Alternative Suppliers of Outputs	Type of Partners Needed	Achievability of Outputs	Feasibility of Delivery (Outputs to Outcomes)
9	Water	Options developed & tested to increase livestock water productivity	E Africa E S W Africa S Asia	LRA/T MRA/T MIA/T	Medium-Long	Medium-High	Leader	P	None?	ARIs NARS	Low-Medium	Medium
10	Diseases	Future changes in prevalence and intensity of key epizootic livestock diseases elucidated	E S W Africa S Asia	All livestock systems	Medium-Long	Medium-High	Contributor	T B P	ARIs OIOs	ARIs NARS OIOs	Low-Medium	Medium-High
11	Diseases	Impacts of "management" diseases elucidated and management options identified	E S W Africa S Asia	MRH/T COAST URBAN	Medium-Long	Medium-High	Contributor	T B P	OIOs	ARIs NARS Other CGs	Low-Medium	Medium-High
12	Biodiversity	Impacts on ecological biodiversity elucidated	E S W Africa S Asia	All livestock systems	Medium-Long	Medium-High	Contributor	T B P	GCC	ARIs NARS Other CGs GCC	Low	Low
13	Biodiversity	Animal breed biodiversity characterised, and a road map developed for future exploitation	E S W Africa S Asia	All livestock systems	Medium-Long	High	Leader	T B P	OIOs	ARIs NARS OIOs	Low	High

Table 9. continued

	Activity Area	Research Outputs	Geographic Focus	System Focus	Time to Outputs	Order-of-Magnitude Cost	ILRI's Role	ILRI Themes involved	Alternative Suppliers of Outputs	Type of Partners Needed	Achievability of Outputs	Feasibility of Delivery (Outputs to Outcomes)
14	Biodiversity	Conserved plant germplasm for future use as feed	E S W Africa S Asia	All mixed systems	Medium-Long	High	Leader	T B P	OIOs	ARIs NARS OIOs	Low	Medium
15	Livestock systems	Impacts on livelihoods identified	E W S Africa S Asia	All livestock systems	Medium	Medium	Leader	T M P	OIOs, e.g. FAO	Other CGs OIOs NARS	Medium	High (e.g. for priority setting internally and externally
16	Livestock systems	Effects on ecosystem goods & services quantified (e.g. nutrient pollution in industrial systems; deforestation links)	E W S Africa S Asia LAC	All livestock systems	Medium	Medium-High	Contributor	T M B P	OIOs, e.g. WRI	Other CGs ARIs OIOs NARS	Low-Medium	Medium
17	Livestock systems	Case studies of livestock's role in poverty alleviation, climate change adaptation and vulnerability reduction	E W S Africa S Asia LAC	All livestock systems	Short-Medium	Low-Medium	Leader	T M B P S	None?	NARS	High	Medium (impacts on the debate)
18	Indirect impacts	Interconnections between human health, livelihood systems and vulnerability elucidated	E W S Africa S Asia	MRH/T COAST URBAN OTHER	Medium-Long	Medium-High	Facilitator?	T M P	GCC OIOs	ARIs GCC OIOs NARS	Low	Low-Medium
19	Impact assessment	Assessment frameworks and trade-off analysis and targeting tools developed	Global	All	Medium	Medium	Contributor/ Leader	T M B P	OIOs?	GCC OIOs Other CGs ARIs	Medium-High	Medium-High

Table 9. continued

	Activity Area	Research Outputs	Geographic Focus	System Focus	Time to Outputs	Order-of-Magnitude Cost	ILRI's Role	ILRI Themes involved	Alternative Suppliers of Outputs	Type of Partners Needed	Achievability of Outputs	Feasibility of Delivery (Outputs to Outcomes)
20	Adaptation	Toolboxes of viable options developed and disseminated	E W S Africa S Asia	MRA/H/T	Medium-Long	Medium-High	Contributor Facilitator	T M B P	None?	Other CGs OIOs NARS ARIs	Medium	Low-Medium
21	Adaptation	Risk management options identified and tested in study sites	E W S Africa S Asia	LGA MRA	Short-Medium	Medium	Facilitator Backstopper	M	NGOs	NARS	Medium-High	Medium-High
22	Mitigation	Framework for biofuel tradeoffs developed and applied	E W S Africa S Asia	All livestock systems	Medium	Medium	Contributor	T M P S	IFPRI[1] SLP	GCC ARIs Other CGs	Medium	Medium
23	Mitigation	Income-generating mitigation options identified in relation to environmental services	S Asia	URBAN MRH/T MIH/T	Medium-Long	Medium-High	Contributor Facilitator	M P	None?	Other CGs ARIs OIOs	Low-Medium	Medium

For systems codes, see Table 10.

Time to outputs: short (1 year), medium (2-5 years), long (> 5years).

Order-of-magnitude cost: low (USD 10,000), medium (USD 100,000), high (USD 1M).

Themes: T, Targeting; M, Markets; B, Biotechnology; P, People, Livestock & the Environment; S, System-wide Livestock Programme

Suppliers & Partners: Other CGs, other CGIAR centres; OIOs, Other International (agricultural and livestock-related) Organisations (e.g. FAO, OIE); NARS, National (and regional) Agricultural Research Systems; ARIs, Advanced Research Institutes; GCC, Global Change (research) Community; NGOs, Non-Governmental Organisations.

Note 1, Entry number 20: IFPRI have funds from the Gates Foundation to develop a framework to assess biofuels. The SLP is commissioning a paper on the trade-offs between energy, food and feed (see Table 7).

Table 10. Agricultural systems for sub-Saharan Africa and South & Southeast Asia (adapted and expanded from Thornton et al., 2006b). Codes used in Table 9.

Code	Short System Description	Sub-Saharan Africa	S &SE Asia
COAST	Coastal artisanal fishing-based systems	Defined D&G	Defined D&G *
FORST	Forest-based systems	Defined D&G	Defined D&G *
PEREN	Highland perennial-based systems	Defined D&G	-
LGA	Livestock only systems, arid-semiarid	Defined S&S, mapped K	Defined S&S, mapped K
LGH	Livestock only systems, humid-subhumid	Defined S&S, mapped K	Defined S&S, mapped K
LGHYP	Livestock only systems, hyper-arid	Defined & mapped K6	-
LGT	Livestock only systems, highland/temperate	Defined S&S, mapped K	Defined S&S, mapped K
MIA	Irrigated mixed crop/livestock systems, arid-semiarid	Defined S&S, mapped K	Defined S&S, mapped K
MIH	Irrigated mixed crop/livestock systems, humid-subhumid	Defined S&S, mapped K	Defined S&S, mapped K
MIHYP	Irrigated mixed crop/livestock systems, hyper-arid	Defined & mapped K6	-
MIT	Irrigated mixed crop/livestock systems, highland/temperate	-	Defined S&S, mapped K
MRA	Rainfed mixed crop/livestock systems, arid-semiarid	Defined S&S, mapped K	Defined S&S, mapped K
MRH	Rainfed mixed crop/livestock systems, humid-subhumid	Defined S&S, mapped K	Defined S&S, mapped K
MRHYP	Rainfed mixed crop/livestock systems, hyper-arid	Defined & mapped K6	-
MRT	Rainfed mixed crop/livestock systems, highland/temperate	Defined S&S, mapped K	Defined S&S, mapped K
OTHER	Other systems, including root-crop-based and root-based mixed	Defined S&S, D&G, mapped K	Defined S&S, D&G *
RITRE	Rice-tree crop systems	Defined D&G	-
TREEC	Tree crop systems	Defined D&G	-
TREEM	Tree crop mixed systems	-	Defined D&G *
URBAN	Built-up areas	Defined JRL	Defined JRL

** System not yet mapped*

Sources: D&G, Dixon & Gulliver (2001). JRL, JRL (2005). K, Kruska et al. (2003). K6, Kruska (2006).

S&S, Seré & Steinfeld (1996)

Scores in the three dimensions were then standardised from 0 to 1 and summed and ranked. Results are shown in Table 11. Activities that rank the highest are those that are important to ILRI, for which ILRI is likely to play a leadership role in the context of few other providers of the research outputs, and where outputs are readily achievable and can be turned into outcomes along well-defined delivery pathways. Also shown in Table 11 are each activity's cost score and time-to-outputs score from Table 9, converted to numbers (from 1 for short time to output and for low cost, to 5 for long time to output and high cost). The cost and time scores are very highly correlated (unsurprisingly, given the crudity of the analysis) and differ only marginally for each activity.

The results should be treated as highly indicative at best, but they are interesting. Unsurprisingly, given the nature of the indicators used, activities that are relatively specific, and whose outcomes are relatively easily achieved, such as priority setting outcomes, tend to score the highest. The first five activities are essentially to do with impact assessment (evaluation and hotspot analysis), of feeds and systems, although this group includes the case studies that can help to inform global debates on the nature of livestock's role in alleviating poverty and reducing vulnerability to climate change - the importance of this stems from the need to contribute to this debate and help to shape it, if possible. This group of activities contains several that should produce outputs in the short- to medium-term, whose costs are relatively modest, and where ILRI is playing the (or a) key role.

The next group of activities (ranked 6 to 10) involve some technology testing (and possibly development), relating to feeds, water productivity, and risk management. The costs of these activities is relatively high, given the field work that would be required, although there are some risk management options that could be assessed within a relatively short time-horizon still. Partnerships for testing the different options would be particularly important for these activities.

The next eight activities (ranks 11= to 16=) score moderately, largely because of limited achievability; there are likely to be considerable technical issues to be overcome in animal breed characterisation in relation to climate change, in identifying and implementing income-generating mitigation options, and in the two disease-related activities (for reasons noted above, to do with the difficulties of assessing probabilistic change), for example.

For the final five activities ranked 19= to 23, there are issues to do with achievability, possibly competing providers of research outputs, and/or lesser importance in relation to ILRI's mandate, compared with higher-ranked alternatives.

The further development of ILRI's portfolio of activities related to climate change is bound to be somewhat opportunistic. Table 12 is an attempt to map on-going activities at ILRI in the area of climate change onto the ranked priorities of Table 11. This also includes expected and possible activities for 2008 and beyond. Activities that are less directly concerned with climate change are shown in Table 12 in italics. This mapping is very approximate, and it is misleading in some respects, as the activity areas shown are inevitably much broader than the scope of specific project activities. For example, while there is some ILRI project work relating to Activity 14, "Impacts on livelihoods identified" (ranked 3=), this is a broad area of work that is likely to need sustained input over the next few years, if we are really to get to grips with the issues involved. However, Table 12 does indicate that some activities are on-going, or reasonably likely to start

Table 11. Activities in Table 9 ranked in descending order according to their importance to ILRI's mandate (I), the nature of ILRI's role and the absence/presence of other providers (O), and the achievability of outputs and outcomes (A). Time to output (1=short, 5=long) and cost (1=low, 5=high), as defined in Table 8, are also shown.

	Activity Area	Research Output	I	O	A	Sum	Rank	Time	Cost
1	Feeds	Localised impacts & hotspots identified	1.00	1.00	1.00	3.00	1	1	1
17	Livestock systems	Case studies of livestock's role	1.00	1.00	0.80	2.80	2	2	2
15	Livestock systems	Impacts on livelihoods identified	1.00	0.83	0.80	2.63	3=	3	3
19	Impact assessment	Assessment frameworks and targeting tools developed	1.00	0.83	0.80	2.63	3=	3	3
20	Adaptation	Toolboxes of viable options developed and disseminated	0.80	0.83	0.50	2.13	5	4	4
9	Water	Options to increase livestock water productivity	0.60	1.00	0.50	2.10	6	4	4
16	Livestock systems	Effects of changes on ecosystem goods & services	0.80	0.67	0.50	1.97	7	3	4
2	Feeds	Rangeland NPP distribution & impacts elucidated	0.60	0.67	0.70	1.97	8	3	3
3	Feeds	Modified crop & residue quality & quantity	0.60	0.83	0.50	1.93	9	5	4
21	Adaptation	Risk management options tested in study sites	0.60	0.50	0.80	1.90	10	2	3
6	Feeds	Feed markets developed	0.60	0.67	0.60	1.87	11=	3	3
13	Biodiversity	Animal breed biodiversity characterised	0.60	0.67	0.60	1.87	11=	4	5
8	Water	Changes in surface and groundwater supply, impacts	0.60	0.67	0.50	1.77	13=	3	3
14	Biodiversity	Conserved plant germplasm for future feed	0.60	0.67	0.50	1.77	13=	4	5
23	Mitigation	Income-generating mitigation options identified	0.60	0.67	0.50	1.77	13=	4	4
10	Diseases	Changes in key livestock diseases	0.60	0.50	0.60	1.70	16=	4	4
11	Diseases	Impacts of "management" diseases elucidated	0.60	0.50	0.60	1.70	16=	4	4
22	Mitigation	Framework for biofuel tradeoffs developed, applied	0.60	0.50	0.60	1.70	16=	3	3
4	Feeds	New feeding strategies developed	0.40	0.33	0.50	1.23	19=	4	3
5	Feeds	Management, production, storage of new feeds	0.40	0.33	0.50	1.23	19=	4	3
7	Feeds	Hotspots of key pests and diseases	0.20	0.50	0.50	1.20	21	3	3
12	Biodiversity	Impacts on ecological biodiversity elucidated	0.20	0.50	0.20	0.90	22	4	4
18	Indirect impacts	Human health, livelihood systems and vulnerability	0.20	0.33	0.30	0.83	23	4	4

soon, in all of the top-twelve-ranked activity areas, with the exception of specific case studies of livestock's role in reducing vulnerability and two feeds activity areas. Basically, work in any of these activity areas is likely to have beneficial impacts on the poor in specific target domains, and further donor funding for many of them may well become available. What the results of the crude ranking exercise do underline, however, is the primacy of incorporating an appropriate climate-change perspective into evaluation and planning. Table 11 suggests that, in particular, well-defined case studies on livestock and vulnerability should be able to produce quick and useful outputs that are unlikely to be replicated by any other organisation. Table 12 indicates that such activity is not explicitly in ILRI's research portfolio at present, and perhaps we need to look at including it.

Also as noted above, however, there are few areas where ILRI is able to take the lead. The implication of this is that partnerships will be key in producing many of the research outputs anticipated in Table 9. While ILRI already has a long list of partners, some discussion is warranted on new potential partners and what they might bring to any collaboration. Access to one possible set of new partners may be provided by the prospective Challenge Programme on Climate Change: members of the Earth System Science Partnership (ESSP), part of the Global Change Community. The Amsterdam Declaration on Global Change in 2001 called for strengthening the cooperation amongst the global environmental research programmes, for greater integration across disciplines, environment and development issues and the natural and social sciences. In response, the four international global environmental change research programmes joined together to form the ESSP. ESSP is made up of DIVERSITAS, the International Programme of Biodiversity Science; the International Human Dimensions Programme on Global Environmental Change (IHDP); the International Geosphere-Biosphere Programme (IGBP); and the World Climate Research Programme (WCRP). It is this group that the CGIAR is working with to develop the Challenge Program on Climate Change and, it is hoped, create a fusion of agricultural scientists and earth system scientists that each bring something different to the collaboration.

The ESSP and its collaborators have expertise in climate modelling tools for generating the future climate scenarios that are critical for assessing climate change adaptation and mitigation strategies, and broad knowledge and experience in data and models of land use and how land management and agricultural management decisions impact on the earth system dimensions of climate, water resources, biodiversity, and soils. It also brings expertise in remote sensing, biogeochemical cycles, hydrology, land degradation, function and valuation of biodiversity, and the social and political dimensions of vulnerability and adaptive capacity. These areas of expertise should form a natural complement to traditional CG centre strengths in agricultural livelihood options for the resource-poor, set within a dynamic market and policy environment.

Another potential source of partners for ILRI activities is the disaster preparedness and response community. A bewildering array of tools and processes has been (and continues to be) developed to improve decision-making to reduce risks and take advantage of opportunities associated with climate variability and change. Many of these are being piloted by development agencies and others to tackle climate-related risks, but there is little formal coordination of efforts, either within the disaster community or within the development community in general. A great deal of this work revolves around a broadly common approach that integrates climate-

Table 12. ILRI projects that are to do with climate change which are on-going, imminent, and possible for 2008, mapped against the ranked activities of Table 11. Activities that are more indirectly linked to climate change are shown in italics.

	Activity Area	Research Output	Rank	ILRI Activity	Status
1	Feeds	Localised impacts & hotspots identified	1	• *SLP Drivers* • TG01	On-going On-going
17	Livestock systems	Case studies of livestock's role	2		
14	Livestock systems	Impacts on livelihoods identified	3=	• BMZ • DFID	On-going Imminent
19	Impact assessment	Assessment frameworks and targeting tools developed	3=	• DFID • CCAA • CCCP	Imminent On-going Possible 2008
20	Adaptation	Toolboxes of viable options developed and disseminated	5	• ASARECA	On-going
9	Water	Options to increase livestock water productivity	6	• *Nile Basin CPWF*	On-going
16	Livestock systems	Effects of changes on ecosystem goods & services	7	• EACLIPSE	On-going
2	Feeds	Rangeland NPP distribution & impacts elucidated	8	• SLP Pastoral CC	On-going
3	Feeds	Modified crop & residue quality & quantity	9		
21	Adaptation	Risk management options tested in study sites	10	• BMZ • CCCP	On-going Possible 2008
6	Feeds	Feed markets developed	11=		
13	Biodiversity	Animal breed biodiversity characterised	11=	• *DAGRIS* • *Genetic diversity maps*	On-going On-going
8	Water	Changes in surface and groundwater supply, impacts	13=		
14	Biodiversity	Conserved plant germplasm for future feed	13=	• Part of Operating Project P4 (Table 7)	On-going
23	Mitigation	Income-generating mitigation options identified	13=		
10	Diseases	Changes in key livestock diseases	16=		
11	Diseases	Impacts of "management" diseases elucidated	16=		
22	Mitigation	Framework for biofuel tradeoffs developed, applied	16=		
4	Feeds	New feeding strategies developed	19=		
5	Feeds	Management, production, storage of new feeds	19=		
7	Feeds	Hotspots of key pests and diseases	21		
12	Biodiversity	Impacts on ecological biodiversity elucidated	22		
18	Indirect impacts	Human health, livelihood systems and vulnerability	23		

related impacts as an additional stressor on systems and livelihoods. The fact that adaptive response capacities are being built into existing decision-making structures in many places by the disaster community would seem to offer a good opportunity for CG centres such as ILRI to tap into these where appropriate. A good overview on some of the tools being developed and tested can be found at www.linkingclimateadaptation.org. There are definitely synergies that should be explored with this community, in terms of collaborative links that may involve the sharing of tools and databases, and the development and use of common analytical and conceptual frameworks. There may also be overlap in terms of targeting and field work that could be explored. Experiences from some of ILRI's work in 2007-08 with different development agencies in Kenya, such as the World Bank, VSF-Belgium, and the FAO disaster programme, should offer conduits to other prospective partners that should be explored.

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To conclude, a few generic points can be made about climate change activities. First, the pace of change regarding public perception and donor response to the climate change issue is extremely rapid. Even 18 months ago, it would have been difficult to predict the degree to which climate change and adaptation would shoot up the list of many donors' priorities. Things are evolving very quickly. ILRI's portfolio of climate change activities will be significantly expanded during 2008 with new activities funded by DFID, IDRC and GTZ/BMZ, for example.

Second, despite the enormous interest in adaptation issues, there are still some key gaps in our knowledge of the possible impacts of climate change on poor livestock keepers in both mixed and pastoral systems, and how their livelihood options may be affected. While a great deal is known about how pastoralists cope with climate variability, for example, more information is needed concerning the nature and extent of the tradeoffs possible between different crop and

Key to projects in Table 12 (see Appendix 1 for more details):

ASARECA: Managing uncertainty: innovation systems for coping with climate variability and change.

BMZ: Supporting the vulnerable: Increasing the adaptive capacity of agro-pastoralists to climatic change in West and Southern Africa using a transdisciplinary research approach.

CCAA: Scoping study on vulnerability assessment for the Greater Horn of Africa.

CCCP: Challenge Programme on Climate Change, Agriculture and Food Security (at the time of writing, the proposal for this challenge programme is still under development and the outcome uncertain).

DAGRIS (& Genetic diversity maps): Domestic Animal Genetic Information System.

DFID: Foundations for climate change impact and adaptation assessment in Ethiopia.

EACLIPSE: Dynamic Interactions among People, Livestock, and Savanna Ecosystems under Climate Change.

Nile Basin CPWF: Increasing water-use efficiency for food production through better livestock management, Challenge Program on Water and Food.

SLP Drivers: Drivers of change in crop-livestock systems.

SLP Pastoral CC: Identifying livestock-based risk management and coping options to reduce vulnerability to droughts in agro-pastoral and pastoral systems in East and West Africa.

TG01: Systems evolution operating project, Targetting Theme.

livestock enterprises, and between on- and off-farm income sources, in different situations. Given the importance of livestock to the resource-poor in Africa and their use in risk management, the lack of information on the livestock-poverty-development nexus urgently needs to be addressed. This is key niche that ILRI needs to exploit to the full.

Third, the targeting of development assistance and adaptation options needs to be much better informed by the use of appropriate scientific information. The gap between knowledge and action is considerable, and this needs to be spanned much more effectively. This applies not only to livestock and climate change issues, but to agricultural development in general. However, there is a key role for ILRI and partners in catalysing work to bridge the knowledge-action divide, and this should revolve around information generated on the likely system-level impacts of climate change on the livelihoods of poor livestock keepers, and what can be done to ameliorate the negative impacts and, in the areas where this may occur, enhance the positive.

Finally, there is a need to further develop activities in the general area of impact assessment. In setting out a research strategy in relation to climate change activities at CIAT, Jones et al. (2007) identified at least two types of impact assessment that are needed: detailed agro-ecological analysis of prospective project target areas that adds the dimension of climate variability and climate change in a meaningful way; and ex-ante (and ex-post) impact assessments that are designed to evaluate potential (and implemented) adaptation and mitigation options and their effects on livelihoods and the trade-offs that arise between income, food security and environmental objectives.

These various issues are coming to the fore in the science plan for the Challenge Program on Climate Change. If this comes about, and indeed even if it does not come about, there are key contributions that ILRI can make to advancing the research agenda on the overlaps between livestock, climate change, and the poor people who depend on livestock for their livelihoods.

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Acronyms

AIACC	Assessments of Impacts and Adaptations to Climate Change
AnGR	Animal Genetic Resources
AOGCM	Atmosphere-Ocean (coupled) General Circulation Model
AR4	Fourth Assessment Report (of the IPCC)
CGIAR	Consultative Group on International Agricultural Research
DFID	Department for International Development
ENSO	El Niño Southern Oscillation
ESSP	Earth System Science Partnership
FAO	Food and Agriculture Organisation of the United Nations
GCM	General Circulation Model
GHG	Greenhouse Gas
HadCM3	United Kingdom Meteorological Office Hadley Centre Coupled GCM
IAASTD	International Assessment of Agricultural Science and Technology for Development
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate Prediction
MA	Millennium Ecosystem Assessment
MTP	Medium-Term Plan
SLP	System-wide Livestock Programme
SSA	Sub-Saharan Africa
SRES	Special Report on Emissions Scenarios

Appendix 1

A Rapid Inventory of ILRI Activities in Climate Change Research

Research projects are listed under the following research areas:

- Targeting and System Change
- Animal Health and Genetic Resources
- Land Use and Natural Resources

1 Targeting and system change area

Crop-livestock productivity impacts of climate change

Involves continental-scale analyses of likely changes in crop and biomass productivity under different scenarios of climate change to 2050 in Africa and Latin America, using high-resolution climate surfaces and crop and biomass models. The work is being expanded to cover several crops and forages, and outputs will help to identify geographic and thematic hotspots of change.

Mapping climate vulnerability and poverty in Africa

Integrates the identification of likely hotspots of climate change in sub-Saharan Africa under different scenarios to 2050 with indicators of vulnerability. Many vulnerable regions are likely to be adversely affected, including the mixed arid-semiarid systems in the Sahel, arid-semiarid rangeland systems and the coastal regions of eastern Africa, and the drier zones of southern Africa. The work will be expanded in 2007-2008 to assist regional organisations provide IDRC's Climate Change Adaptation in Africa Research and Capacity Development Programme (CCAA) with targeting and impact assessment outputs, with a focus on linking scientific information with policy formulation and implementation. In 2008, DFID will support a higher-resolution country case study for targeting and monitoring purposes.

Projects are "Scoping study on vulnerability assessment for the Greater Horn of Africa" (CCAA), and "Foundations for climate change impact and adaptation assessment in Ethiopia" (DFID). There may be links between the latter project and an on-going activity under the Challenge Programme on Water and Food, "Increasing water-use efficiency for food production through better livestock management", which is seeking to improve food security, reduce poverty and enhance agroecosystem health by managing livestock for more effective overall use of water resources in the Nile basin.

Targeting and priority setting of climate change adaptation options

This encompasses a study of the climate change adaptation options in the context of the ASARECA countries. This work intends to review the investment options and technological interventions proposed in the ASARECA Strategic Plan for sustained growth and poverty reduction in the region from a climate change perspective. It will examine them in terms of their potential susceptibility and risk to climate change impacts in order to draw a set of priority adaptation options for the different ASARECA recommendation domains. The work will be carried out in close collaboration with the ASARECA Networks and other CG Centres (the project, “Managing uncertainty: innovation systems for coping with climate variability and change”).

Livestock futures

This encompasses several sets of activities:

Scenario analysis, building on existing work such as the Millennium Ecosystem Assessment , with a focus on impacts of different story lines on livestock sector development to 2030 and beyond;
Modelling work to derive meaningful projections of livestock numbers into the future, associated with changes in production system distribution, under a range of different scenarios; and
Studies that elucidate some of the key natural resource impacts of the scenarios in terms of feed resource access and availability, methane emissions, and water use in livestock systems.
Outputs from this work will be used to help set priorities for ILRI and partners, and to suggest ways in which the research portfolio might be modified to help attain the goals of the institutions involved. Activities in this area include “Drivers of change in crop-livestock systems” funded by the System-wide Livestock Programme (SLP), and some of the activities in TG01, the systems evolution operating project of ILRI’s Targetting Theme.

Climate change assessment tools

In collaboration with CIAT and others, development and application of a system to generate characteristic daily weather data from downscaled, high-resolution climate surfaces, derived from several Global Circulation Models and SRES scenarios. Such a tool is an essential element in many priority-setting and impact-assessment activities related to climate change.

Trajectories of Change in Crop-Livestock Systems (TOC)

Providing analytical tools to conduct systematic comparisons of crop-livestock systems and to predict changes in crop-livestock intensity and evolution in response to global drivers of change, including climate, built around a case-study in central Kenya. This work has provided information for several fora that have looked at possible future scenarios of agricultural development in Kenya.

Impacts of climate change in northern Kenya

Livestock carrying capacities have been estimated in northern Kenya under a range of different climate change scenarios, using simple grassland and livestock productivity models, to assist VSF-Belgium in targeting and prioritising activities. Outputs from this work are informing strategic decisions concerning the type of development assistance that may be needed in arid-semiarid pastoral systems in the coming years.

Kenya Adaptation to Climate Change in the Arid Lands (KACCAL).

Anticipating, adapting to and coping with climate risks in Kenya: Operational recommendations for KACCAL. A KACCAL pre-activity, consisting of literature reviews, household surveys, and analyses on the effects of climate change in marginal. This study was designed to inform and recommend various programs, policies and processes to help KACCAL meet its objective of helping vulnerable populations to adapt to the adverse impacts of climate change. As part of this study a synthesis of the available information on climate change impacts in East Africa and Kenya was conducted.

Supporting the vulnerable: Increasing the adaptive capacity of agro-pastoralists to climatic change in West and Southern Africa using a transdisciplinary research approach.

The goal of this project, funded by BMZ, is to increase the adaptive capacity of agro-pastoralists, who are one of the most vulnerable groups in Africa, to climate variability and the expected effects of future climate change. The purpose is to co-generate methods, information and solutions between local communities, local and international scientists, policy makers and other actors involved in climate change and adaptation programmes, for coping mechanisms and adapting strategies to climate change and variability in West and Southern Africa, and more particularly in Mali and Mozambique. The project aims to deliver integrated outputs that document the effects of climate variability and change on primary productivity, that document agro-pastoralists' coping mechanisms to deal with climate variability, that identify technical options and policy entry points for supporting the implementation of priority livestock-based adaptation options, and that increase awareness of the likely impacts of climate variability and change, and to provide information for making decisions in relation to adaptation options for different conditions.

2 Animal health and genetic resources

Climate change and the implications for animal genetic resources

A review study on the climate change and environmental degradation, and the policy implications on farm animal genetic resources in Africa, part of ILRI's contribution to the FAO-Wageningen exchange project.

Impacts of population and climate change on trypanosomiasis to 2050

An Africa-wide study is currently looking at projected changes in the distribution of tsetse species to 2050, and how this may affect control strategies for different livestock systems. Broad-scale analyses have been completed. This work will continue through the GEF project in West Africa, to assess levels of zebu introgression into taurine populations (which is partly dependent on tsetse distributions), and to match livestock genotypes more closely with changing production systems and the environment.

Georeferencing of ILRI's "Domestic Animal Genetic Information System'' (DAGRIS).

Livestock productivity and breed distribution information are currently being georeferenced for African cattle, sheep, and goats. This information overlaid with climatic and ecological GIS information will provide entry points for breed selection adapted to specific environmental parameters (e.g. drought tolerance).

Mapping of genetic diversity of indigenous livestock.

Molecular characterisation studies are being done both at large geographical scale (continental studies) and in detail at the country level (such as sheep in Ethiopia), providing information on relationships between diversity and agroecological zones, in both quantitative and qualitative (uniqueness) terms. This work will provide baseline starting information on the effect of climatic change on livestock diversity.

3 Land use and natural resources

Climate-Land Interaction Project (CLIP)

A collaboration between Michigan State University, ILRI, and others to understand the magnitude and nature of the interaction between land use and climate change at regional and local scales. These linkages are being examined through characterising and modelling agricultural systems, land use, the physical properties of land cover, and the regional climate in East Africa. Results include scenarios of climate change and effects on productivity of mixed crop-livestock systems. CLIP will also assess the impacts of climate change on the distribution and composition of grass species in Kenya and their effect on grazers. Country reports are being developed on adaptations to climate change in Kenya, Uganda, and Tanzania.

Trade-offs between carbon sequestration and farm income in smallholder agricultural systems in West Africa

This study forms one component of the Soil Management CRSP project "Measuring and Assessing Soil Carbon Sequestration by Agricultural Systems in Developing Countries," led by the University of Florida. This study assesses the income-generating and carbon-sequestration potential of different crop and livestock management strategies. Results of the study will provide information on the prospect of smallholders' participation in payment schemes under the Clean Development Mechanism of the Kyoto protocol as well as household modelling tools that can be used in other assessments of climate change impacts in different places.

Dynamic Interactions among People, Livestock, and Savanna Ecosystems under Climate Change (EACLIPSE)

The project is addressing the question, what are the key characteristics of and dynamics between coupled human-biophysical systems in savannas in East Africa under climate change? This question will be examined in an ecological system where the impacts of climate change upon vegetation and society are expected to be particularly acute. A comprehensive methodological approach to modelling and statistical analysis of climate, land management, and ecosystem dynamics is being used at two scales: the local scale, where human decisions are made and ecosystem dynamics are most evident, and at the regional scale, where the cumulative effect of human activity and ecosystem change may significantly impact climate. Interaction between scales and temporal dynamics including feedback effects form the crux of the analysis of the coupled natural-human system.

Identifying livestock-based risk management and coping options to reduce vulnerability to droughts in agro-pastoral and pastoral systems in East and West Africa.

The purpose of this project, funded by the System-wide Livestock Programme, is to identify intervention options (technical, policy, and institutional) that reduce the vulnerability of livestock keepers and/or communities dependent on livestock for their livelihoods to climatic shocks, particularly droughts, in pastoral and agro-pastoral systems in East and West Africa and the vulnerability of livestock to shocks. This purpose addresses the need to reduce vulnerability of both the pastoralists/agro-pastoralists and their livestock to droughts (securing livestock assets). Securing livestock assets is important in view of the roles they play in drought mitigation and coping strategies in pastoral and agro-pastoral systems.

Appendix 2

ILRI publications related to climate change work, listed chronologically

1. Reid R S, Kruska R L, Deichmann U, Thornton P K and Leak S G A (2000). Will human population growth and land-use change control tsetse during our lifetimes? Agriculture, Ecosystems and Environment 77, 227-236.
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4. Jones P G and Thornton P K (2003). The potential impacts of climate change in tropical agriculture: the case of maize in Africa and Latin America in 2055. Global Environmental Change 13, 51-59.
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6. Thornton P K, Reid R S and Kruska R L (2003). Adapting to global change in Africa: studying the implications for rangelands. Invited paper for the 7th International Rangelands Congress, Durban, South Africa, 26 July-1 August 2003.
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10. Jones P G and Thornton P K (2005). How crop production will be affected by climate change in Africa and its repercussions on the continent. Pp 26-37 in C Robledo, M Kannine, L Pedroni (eds), Tropical forests and adaptation to climate change: in search of synergies. CIFOR, Bogor.
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12. Thornton PK, Jones P G, Owiyo T, Kruska R L, Herrero M, Kristjanson P, Notenbaert A, Bekele N and Omolo A, with contributions from Orindi V, Ochieng A, Otiende B, Bhadwal S, Anantram K, Nair S, Kumar V and Kelkar U (2006). Mapping climate vulnerability and poverty in Africa. Report to the Department for International Development, ILRI, Nairobi, Kenya, May 2006, 200 pp. Online at http://www.dfid.gov.uk/research/mapping-climate.pdf
13. Thornton P K, Robinson T P, Kruska R L, Jones P G, McDermott J Reid R S (2006). Cattle trypanosomiasis in Africa to 2030. Report for the Foresight Project on Detection of Infectious Diseases, Department of Trade and Industry, UK Government, 11 pp.
14. Herrero M, Thornton P K, Kruska R L and Reid R S (2008). The spatial distribution of methane emissions from African domestic ruminants to 2030. Agriculture, Ecosystems and Environment 16, 122-137.
15. Gonzalez-Estrada E, Rodrigues L C, Walen V K, Naab J B, Koo J, Jones J W, Herrero M and Thornton P K (2008). Carbon sequestration and farm income in West Africa: Identifying best management practices for smallholder agricultural systems in northern Ghana. Ecological Economics (in press).
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