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Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change

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ABSTRACT

The impacts of climate change are expected to be generally detrimental for agriculture in many parts of Africa. Overall, warming and drying may reduce crop yields by 10–20% to 2050, but there are places where losses are likely to be much more severe. Increasing frequencies of heat stress, drought and flooding events will result in yet further deleterious effects on crop and livestock productivity. There will be places in the coming decades where the livelihood strategies of rural people may need to change, to preserve food security and provide income-generating options. These are likely to include areas of Africa that are already marginal for crop production; as these become increasingly marginal, then livestock may provide an alternative to cropping. We carried out some analysis to identify areas in sub-Saharan Africa where such transitions might occur. For the currently cropped areas (which already include the highland areas where cropping intensity may increase in the future), we estimated probabilities of failed seasons for current climate conditions, and compared these with estimates obtained for future climate conditions in 2050, using downscaled climate model output for a higher and a lower greenhouse-gas emission scenario. Transition zones can be identified where the increased probabilities of failed seasons may induce shifts from cropping to increased dependence on livestock. These zones are characterised in terms of existing agricultural system, current livestock densities, and levels of poverty. The analysis provides further evidence that climate change impacts in the marginal cropping lands may be severe, where poverty rates are already high. Results also suggest that those likely to be more affected are already more poor, on average. We discuss the implications of these results in a research-for-development targeting context that is likely to see the poor disproportionately and negatively affected by climate change.

1. Introduction

Agricultural systems in developing countries are changing rapidly in response to a variety of drivers. Globally, human population is expected to increase from more than 6.5 billion today to nearly 9.2 billion by 2050 (UNPP, 2008). About 1 billion of this increase will occur in Africa. At the same time, rapid urbanisation is expected to continue in developing countries. By the end of 2008, more than half the global human population (3.3 billion) will be living in urban areas. By 2030, this number will have increased to almost 5 billion: the next few decades will see unprecedented urban growth particularly in Africa and Asia (UNFPA, 2008). Furthermore, the global demand for livestock products will continue to increase significantly in the coming decades (Delgado et al., 1999), driven by urbanisation, population growth and income

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increases. This increased demand is largely based in developing countries (Delgado, 2005). The trends in demand will be for both increased quantity, especially as incomes rise from USD 2 to 10 per day, and for increasing quality, particularly among urban consumers who purchase livestock products from supermarkets (Thornton et al., 2007).

In addition to all this, the climate is changing. Recent climate model projections suggest an increase in global average surface temperature of between 1.8 and 4.0 °C to 2100, the range depending largely on the scale of fossil-fuel burning between now and then and on the different models used (IPCC, 2007). At mid- to high latitudes, crop productivity may increase slightly for local mean temperature increases of up to 1–3 °C, depending on the crop, while at lower latitudes, crop productivity is projected to decreases for even relatively small local temperature increases (1–2 °C) (IPCC, 2007). In the tropics and subtropics in general, crop yields may fall by 10–20% to 2050 because of warming and drying, but there are places where yield losses may be much more severe (Jones and Thornton, 2003). In addition to these longer-term changes in climate, shorter-term changes are also anticipated. For example, there will be changes in the frequency and severity of extreme climate events, and these will have significant consequences for livelihoods, natural resources, food production, and food security. Increasing frequencies of heat stress, drought and flooding events are likely, and 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).

Taking these drivers together, the trajectory of agricultural systems in the coming decades in different places may be difficult to foresee in much detail, but they will certainly be extremely dynamic. On the one hand, the increased demand for crop and livestock products is going to have to be met from somewhere, and one development challenge is to maximize the benefits to the poor in this demand-led income opportunity. The poor will be able to play a greater role in some livestock production and market chain systems than others. Smallholders are major players in the dairy sector, for example – indeed, almost all the meat and milk in Africa is produced in agro-pastoral and mixed systems (de Haan et al., 1997) – while industrial systems are the major actors in the rapidly growing poultry market. On the other hand, climate and other global change drivers may make it difficult for smallholders to take advantage of the demand-led income opportunities that will arise. The impacts of climate change on agricultural systems are likely to be highly heterogeneous, both spatially and temporally. Some places in the highlands of sub-Saharan Africa (SSA) may see improvements in conditions for crop growth as a result of increasing temperatures and rainfall amounts, and there may be opportunities for smallholders to intensify and/or diversify production in these areas. There are other places where the changing climate means that the livelihood strategies of rural people will have to change, to preserve food security and provide income-generating options. These are likely to include areas of Africa that are already marginal for crop production. As these become increasingly marginal, then livestock may provide an alternative to cropping. In many of the semiarid systems in sub-Saharan Africa, livestock production enables farmers to diversify incomes, helping to reduce income variability—indeed, livestock are a crucial coping mechanism for poor and vulnerable people in variable environments (LID, 1999).

Given the heterogeneity of the likely impacts of climate change and of households' ability to deal with it, there is a need for detailed information on the impacts on agricultural systems, so that effective adaptation options can be appropriately targeted. In this paper, we summarise some existing broad-scale analysis that quantified possible changes in indicator crop yields and length of growing periods in Africa. We build on this work in an attempt to locate ''transition zones'' where climate shifts between now and 2050 may make cropping increasingly risky, and where by extension livestock keeping may increase in importance as a livelihood strategy. We characterise these transition zones in terms of their human and animal populations and poverty rates, using appropriate proxies. Results of the analysis are discussed in terms of their implications for the targeting of adaptation options for poverty alleviation. We conclude by highlighting some methodological and information gaps that, once filled, could increase our effectiveness in pro-poor targeting.

2. Methods

In previous work we have carried out broad-scale analyses at the continental level that quantify possible changes in the length of the growing period and in indicator crop yields in the coming decades under a range of different scenarios, to help identify people who are likely to be particularly vulnerable to such changes. Prospective changes in the length of growing period (LGP) for Africa were projected to 2050 for a variety of combinations of General Circulation Model (GCM) and greenhouse-gas (GHG) emission scenarios in Thornton et al. (2006). These ''hotspots'' of LGP change were then used in conjunction with indicators of current vulnerability to identify agricultural systems that could be considered highly vulnerable in the future, to assist in priority setting and allocating research resources. In Jones and Thornton (2003), we demonstrated possible impacts on maize production in Africa and Latin America to 2055, using high-resolution methods to generate characteristic daily weather data for driving a detailed simulation model of the maize crop. Those results indicated an overall reduction of 10–20% in maize production to 2055, equivalent to losses of $2 billion per year. However, the aggregate results hide enormous variability, and Jones and Thornton (2003) identified three major types of (simulated) response of the maize crop to climate change:

1. Crop yields decrease, but to an extent that can be handled by breeding and agronomy. The history of breeding and agronomic research would suggest that, depending on circumstances and the crops involved, yield losses of 25–40% could potentially be dealt with in this way without great difficulty. For example, there have been periods during the history of maize breeding in East and southern Africa when yield growth rates have been sustained at nearly 5% per year over several years (Smale and Jayne, 2003).

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2. The crop benefits from climate change, as for example in highland areas where temperature limitations on crop growth are relaxed in the coming decades due to gradual warming. These places may present smallholders with new opportunities for income generation.
3. Crop yields decline so drastically that major changes may be needed to the agricultural system, and in some places perhaps human populations may even be displaced.

We designed and carried out some analyses to look at the third response in more detail, specifically at a relatively common transition in Africa, that between cropping and livestock keeping. Given the prevalence of smallholder mixed crop–livestock systems in Africa, this transition is perhaps better described as the changing emphasis that householders place on crop and livestock enterprises and the shifting ability of these enterprises to sustain the household and to provide income and food security.

There is an extensive literature, with a long history, on the relationships between agro-ecology and farming systems in Africa. Traditionally, pastoralists, agro-pastoralists and croppers over the centuries have invented a very diverse portfolio of ways to deal with the spatial and temporal variability of production potential (or the ability of specific pieces of land to support animals and crops) (Campbell, 1990). The planting of higher-producing or more drought-tolerant crops, or the use of higher-potential or more drought-tolerant livestock genotypes and species, are ways of moving along the continuum from wetter to drier conditions. Moving livestock large distances to find productive pastures, changing the relative emphasis in the farming system on crop versus livestock activities, and abandoning cropping activities altogether, are all ways in which people have dealt with climate variability in the past, and these will provide options for dealing with a changing climate in the future.

Many of these ways of adapting have been well documented. For example, the Samburu of northern Kenya are traditionally a cattle-keeping people and have long had close associations with several camel-keeping neighbours. However, it is only in the last two or three decades that they themselves have begun to adopt camels as part of their livelihood strategy, a change that is ascribed by Sperling (1987) to a decline in their cattle economy from 1960 onwards, caused by drought, cattle raiding, and epizootics. Changes in herd composition within species have also been documented. ‘‘FulBe herders in Nigeria, faced with rapidly vanishing grass in the semiarid zone, have switched their herds from the Bunaji breed, which depends on grass, to the Sokoto Gudali, which can digest browse much more easily’’ (Blench and Marriage, 1999).

Our focus here was to identify areas of SSA where one particular type of transition in livelihood strategies might occur: a shifting emphasis between marginal cropping and livestock keeping. We hypothesised that the choices people make between cropping and keeping livestock in marginal areas are related to some extent to the risk of cropping season failure: as the probability of complete crop failure increases, shifts to livestock keeping, and/or more dependence on livestock keeping, are increasingly likely.

To indicate where such transition areas might be, we started from two classification schemes of the agricultural systems of Africa that were amalgamated in Thornton et al. (2006). The Seré and Steinfeld (1996) system classification is based on livestock systems, and this was expanded to include some of the farming systems defined in Dixon et al. (2001). We did this by taking version 3 of the Seré & Steinfeld classification (Kruska et al., 2003; Kruska, 2006), and overlaying those systems classified as ‘‘non-livestock systems’’ with the Dixon et al. (2001) classification (Table 1). For all non-urban areas, we thus have a classification with three basic types of system: rangeland-based livestock systems (LGA, LGH, LGHYP and LGT in Table 1); mixed crop-livestock systems, either irrigated (MI) or rain-fed (MRA, MRH, MRHYP and MRT); and non-livestock systems (the coastal, forest-based, perennial, rice-tree crop, and tree crop systems, and a category containing various root-based systems). As might be expected, there are some mismatches and inconsistencies in this combined classification, arising primarily because of the very different ways in which the two classifications were derived. An example is the coastal artisanal fishing system, which has goats and poultry (Dixon et al., 2001)—here these are classified as systems with no livestock. However, given the continental scale of these datasets, the matching between the two systems is relatively consistent. For the analyses described here, given that our focus is on SSA, we collapsed the mixed crop–livestock irrigated system categories into one (Table 1).

For these systems (which include the highland areas where cropping intensity may increase in the future because of more favourable cropping conditions), we estimated the probabilities of failed seasons for current climate conditions. To do this, we used a high-resolution dataset of climate normals for the period 1960–1990 (WorldCLIM: Hijmans et al., 2005) and methods based on MarkSim, a statistical daily weather generator (Jones and Thornton, 2000; Thornton et al., 2006). The WorldCLIM climate grid comes at a resolution of 1 km, but to save computation time, we aggregated WorldCLIM to a resolution of 10 min of arc (i.e., pixels at the equator that are about 18 km square). The rest of the analysis was done at this resolution.

For every pixel, we calculated three primary variables, using 100 years of simulated daily weather data and then calculating the means of the following variables:

Length of growing period: This is the average number of growing days per year, and can be interpreted as (among other things) a proxy for the number of grazing days. A growing day is a day in which the average air temperature exceeds 6 °C and the ratio of actual to potential evapo-transpiration exceeds 0.35:

$$\mathrm{Tav} \geq 6\,^{\circ}\mathrm{C} \quad \text{and} \quad \frac{\mathrm{EA}}{\mathrm{ET}} \geq 0.35.$$

These are calculated on a daily basis using methods outlined in Jones (1987), which include running a daily water balance programme. The growing period or ‘‘season’’ is determined to have started as soon as five consecutive growing days have occurred. The season has ended once 12 consecutive non-growing days (or ‘‘stress’’ days) have occurred. Once a season has started, a day is designated a ‘‘stress day’’ if the temperature and evapo-transpiration conditions above are not met.

Failure rate of the primary growing season: This is the failure rate of the longest (average) growing season, which may not

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Table 1 – Agricultural systems used in the analysis for all areas not classified as urban (adapted from Thornton et al., 2006)

Code	Seré and Steinfeld (1996) System Category	Code	Dixon and Gulliver (2001) System Category
LGA	Livestock only systems, arid-semiarid		
LGH	Livestock only systems, humid-subhumid		
LGHYP	Livestock only systems, hyper-arid		
LGT	Livestock only systems, highland/temperate		
MI	Irrigated mixed crop/livestock systems, arid-semiarid		
MRA	Rainfed mixed crop/livestock systems, arid-semiarid		
MRH	Rainfed mixed crop/livestock systems, humid-subhumid		
MRHYP	Rainfed mixed crop/livestock systems, hyper-arid		
MRT	Rainfed mixed crop/livestock systems, highland/temperate		
	Non-livestock systems	COASTAL	Coastal artisanal fishing-based systems
		FOREST-BASED	Forest-based systems
		PERENNIAL	Highland perennial-based systems
		RICE-TREE CROP	Rice-tree crop systems
		TREE-CROP	Tree crop systems
		OTHER	Other systems, including root-crop-based and root-based mixed

necessarily correspond to the traditional ‘‘long-rains’’ season in bimodal environments. A season is defined as ‘‘failed’’ if, in any year, it never starts (as defined above), or if there are fewer than 50 growing days, or if more than 30% of the days within a season proper (that has started and ended) are stress (non-growing) days.

Reliable crop growth days: Some pixels in SSA have more than one growing season on average per year, as defined above. We calculated the Reliable Crop Growth Days (RCGD) per year over n seasons per year as

$$\mathrm{RCGD} = \sum_{i-1}^{n} \text{season length}_i \times (1 - \text{failure rate})_i$$

where the failure rate is as calculated above for all n seasons in the pixel. This can be taken as a proxy for the long-term expectation of the number of reliable cropping days per year, which in some pixels may be spread out across several seasons.

These three variables were calculated for current conditions using WorldCLIM, and then for conditions in 2050 using four combinations of GCM data (the UK’s Hadley CM3 model and the Max Planck Institute’s ECHam4 model) for a higher and a lower greenhouse-gas emission scenario (A1FI and B1, respectively). These SRES (Special Report on Emissions Scenarios) scenarios describe alternative future conditions in relation to greenhouse gas emissions, human population growth, economic growth, and technology, for example, but do not consider agricultural adaptations explicitly (Nakicenovic et al., 2000). The dataset of Mitchell et al. (2004) was used, and the relatively coarse GCM data were downscaled to 10 arc-minutes using the methods of Jones and Thornton (2003).

Ideally, transition zones might best be defined by comparing the probabilities of season failure in cropped and uncropped areas, to derive an estimate of the ‘‘acceptable’’ limit for failed seasons—in other words, the limit below which croppers no longer believe that it is worthwhile to plant a crop.

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This would require a very high-resolution crop distribution dataset, because at the margins of cropping, cropped areas are likely to be small and consequently difficult to pick up from satellite imagery. This is one of the reasons why a land-cover dataset such as GLC 2000 (JRC, 2005), for example, tends to under-represent cropped areas. We thus used an alternative method to define transition zones. If we use maize as an example of a widely grown indicator crop, then maize cropping is generally considered to be marginal in areas with an LGP of between 121 and 150 days per year, and only some of the millets may be appropriate in areas with a shorter LGP (Nachtergaele et al., 2002). Taking the lower limit of this range as a conservative cut-off point for maize cultivation, 120 days LGP can be expressed in RCGD equivalents, which we found to be approximately 90 RCGD. Accordingly in the analysis below, we defined ''transition zones'' to be areas with 90 or more RCGDs per year in 2000 but with less than 90 RCGDs in 2050. For the purposes of this paper, we further stipulated that these transition zones should be within the mixed rainfed arid–semiarid system (MRA, Table 1). There are of course likely to be other areas in the arid–semiarid rangeland-based system (LGA) that cross the threshold of 90 RCGDs between 2000 and 2050. These areas will present different problems to the pastoral communities located in such places—a significant loss in the number of grazing days per year may have serious repercussions, for example, but such problems are not the focus of this analysis.

To characterise these zones where there are substantial changes in the RCGDs, we used several publicly available data sets:

- An accessibility or cost distance dataset, which gives the travel time in minutes to the nearest city with a population in excess of 250,000, based on the estimated travel time to cross each pixel in relation to land cover, slope, elevation, the roads network, any railways, rivers, and water bodies (Nelson, 2007).
- Human population density (number per square km) for 2000, from GRUMP (2005).
- Cattle density (number per square km) for 2000, from Robinson et al. (2007).
- Global distribution of poverty proxies, for many countries at sub-national scale: the percentage of children under 5 who are stunted (low height for age, a measure of chronic undernutrition); the infant mortality rate (number of deaths of infants in their first year per 1000 live births); and the percentage of children under 5 who are underweight for their height (wasting, a measure of acute malnutrition); data available through http://sedac.ciesin.columbia.edu/povmap/.

3. Results

Simulated failure rates of the primary season (number of failed seasons per 100 years as a percentage) and their changes to 2050 are shown in Fig. 1 for the four combinations of GCM and emission scenario. Changes in the number of RCGDs are shown in Fig. 2.

Season failure rates are projected to increase to 2050 in all systems in Africa, except in the hyper-arid rangeland systems (LGHyp) and the irrigated mixed systems (Fig. 1). Some of the increases in failure rates are substantial. In the MRA (mixed rainfed arid–semiarid) systems, for example, failure rates are projected to increase from 18 to 30%, depending on the GCM–scenario combination, an increase in season failure from nearly 1 year in 6 to 1 year in 3. RCGDs decrease in all systems (Fig. 2). Again for the MRA system, the RCGDs decrease from 99 to 73 or so for the high-emission scenario. Similar decreases are found for changes in LGP (results not shown), for up to 37 days on average for the continent for the LGH (rangeland humid–subhumid) systems.

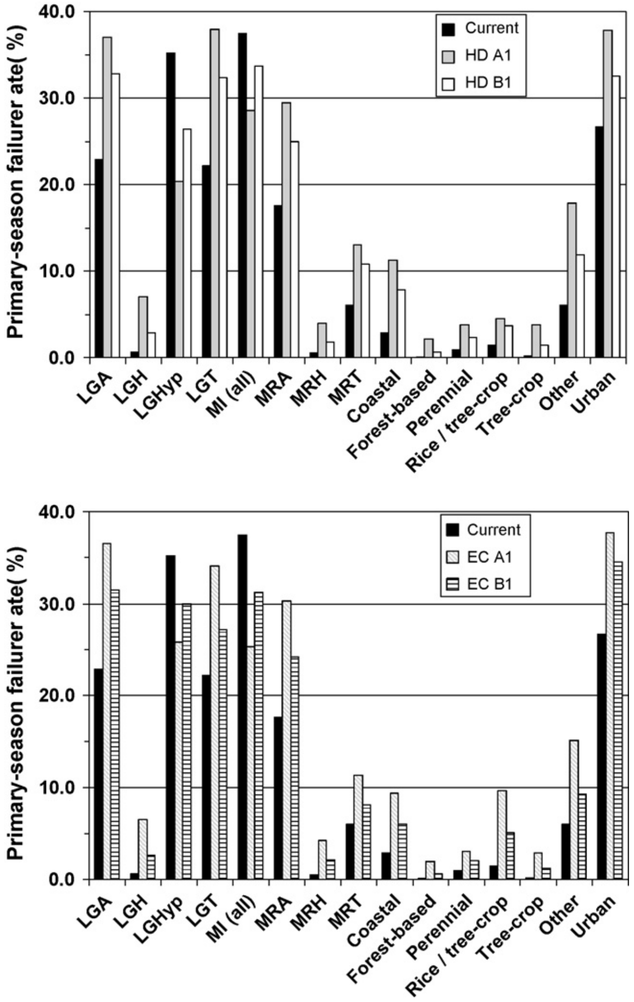

Fig. 1 – The simulated failure rate of the primary season (%) by agricultural system for current conditions and in 2050 for a higher (A1FI) and lower (B1) emission scenario and the Hadley CM3 climate model (HD, top panel) and the ECHam4 climate model (EC, lower panel). For system codes, see Table 1.

Figs. 1 and 2 indicate clear differences between the higher- and lower-emission scenarios, although these are generally differences of degree rather than direction. There are also some differences in downscaled climate impacts between the two GCMs used, although it is hard to pick up much consistency in these. In the coastal systems, for example, the HadCM3 model projects greater losses of RCGD to 2050 for

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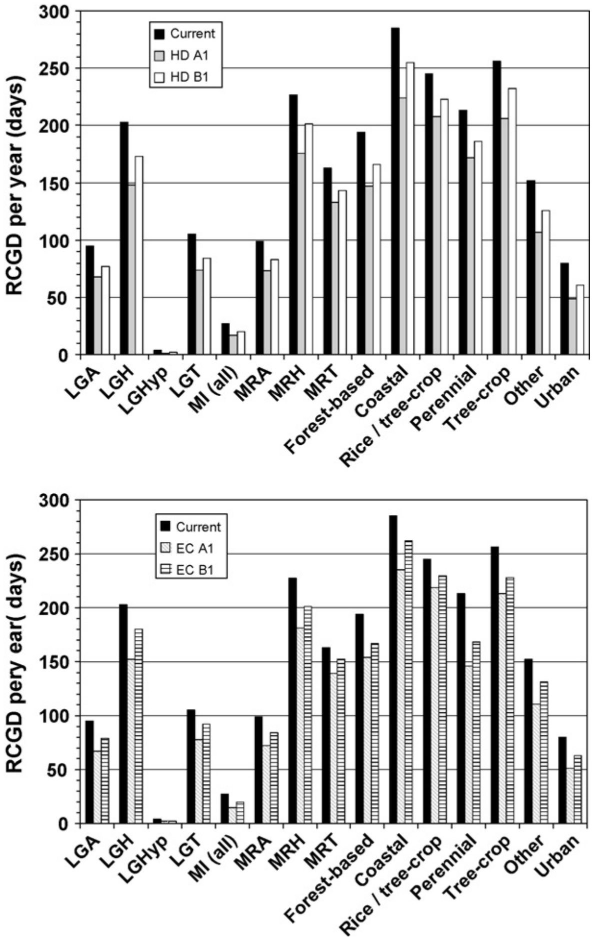

Fig. 2 – The number of simulated Reliable Crop Growth Days (RCGD) per year by agricultural system for current conditions and in 2050 for a higher (A1FI) and lower (B1) emission scenario and the Hadley CM3 climate model (HD, top panel) and the ECHam4 climate model (EC, lower panel). For system codes, see Table 1.

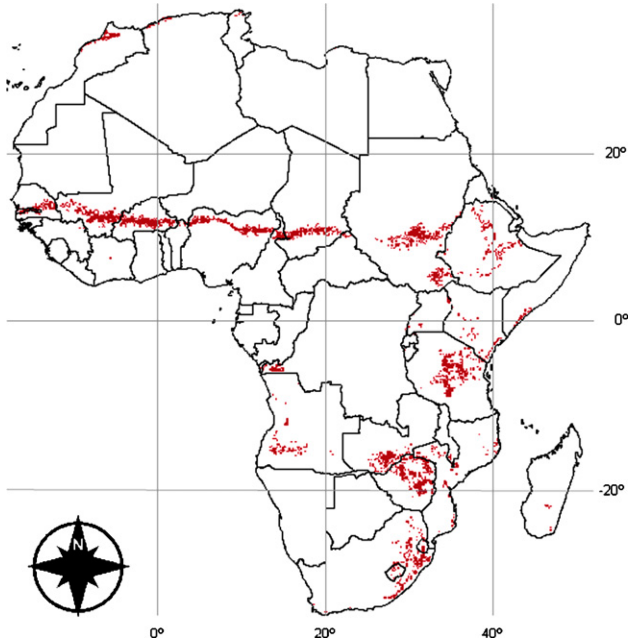

Fig. 3 – Transition zones in the mixed rainfed arid–semiarid system, in which the Reliable Crop Growing Days (RCGD) falls below 90 between 2000 and 2050, as projected using the HadCM32 model and the A1FI scenario.

the A1FI scenario than the ECHam4 model, although for the rice/tree-crop systems, it is the other way round (Fig. 2).

It is also clear from Figs. 1 and 2 that not all of these projected changes will have similar consequences. The changes in season failure rates for the wetter systems are generally rather muted, irrespective of the GCM–scenario combination used. Similarly, the changes simulated in RCGDs for the wetter unimodal systems are not likely to be all that significant from an agronomic perspective, although these changes may be of more importance in the bimodal rainfall areas of Africa where multiple cropping seasons are the norm.

Simple spatial analysis allowed us to identify the areas in the mixed rainfed arid–semiarid (MRA) system where RCGDs moves below 90 days between 2000 and 2050—these are areas where maize cultivation, already marginal, will basically no longer be possible as a "normal" agricultural activity. These areas are mapped in Fig. 3, for the HadCM3 model and the A1FI scenario. Transition zones defined in this way are quite widespread; they include a band across West Africa between latitudes 10 and 12°N, mid-altitude zones in eastern Africa, parts of coastal eastern and south-eastern Africa, and some mid-altitude areas running through central Tanzania, Zambia, Zimbabwe and the Republic of South Africa.

These zones are characterised in Table 2, in terms of their area, human population, cattle, sheep and goat populations, accessibility, and three poverty proxies. Values of these characteristics for all of Africa are included there also, either as totals or as averages. Depending on the combination of GCM and emission scenario, these transition areas make up a maximum of 3% of the land area of the continent. Although these are arid–semiarid mixed systems, these areas currently support up to 35 million people and up to approximately 23 million Tropical Livestock Units (TLUs) of cattle, sheep and goats. These areas have a mean accessibility index of about 500 (i.e., a travel time to the nearest centre with a population of at least 250,000 people of 500 min). Regardless of the CGM-scenario combination used, these transition zones have higher levels of poverty than the continental average, in terms of infant mortality rates, stunting rates (chronic undernutrition), and wasting rates (acute malnutrition).

These transition zones were then stratified by accessibility, on the basis that smallholders who are closer to large markets may have different livelihood options available to them, compared with more remote households. An accessibility index of 200 was chosen—a travel time to and from the market of nearly 7 h is certainly burdensome, but it is feasible for a smallholder to take produce to a market that is 200 min away, sell it, and return home all on the same day. Characteristics of these transition zones with good and poor access are shown in Table 3. As might be expected, the areas of the transition zones with good accessibility are very much smaller than those areas with poor accessibility, and their human population density is

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Table 2 – Characteristics of the MRA transition zones (areas in the mixed rainfed arid–semiarid system that are projected to move from >90 Reliable Crop Growing Days (RCGDs) in 2000 to <90 RCGDs in 2050) for four combinations of climate model (Hadley CM3, HD; ECHam4, EC) and a higher- and lower-emission scenario (A1FI and B1, respectively)

Characteristic	Africa[a]	HD A1FI	HD B1	EC A1FI	EC B1
Area (km^2)[b]	30,309,750	919,296	581,058	932,976	471,276
Human population, million (2000)	795.67	33.71	20.95	35.73	17.66
Cattle population, million	229.26	20.22	13.24	19.43	10.09
Sheep population, million	237.43	16.40	10.70	16.71	9.79
Goat population	213.71	15.95	9.92	16.08	8.51
Accessibility[b]	950	523	524	498	493
Infant mortality rate/1000 births	87.5	92.0	90.0	92.0	87.0
Stunting rate (%)	31.1	33.7	34.0	33.7	31.5
Wasting rate (%)	24.2	26.7	27.0	27.0	25.0

[a] Area and population data are totals from FAOSTAT. Accessibility and poverty proxies are averages that are calculated from the datasets cited in the text.

[b] Minutes of travel time to a town or city with a population of more than 250,000 (Nelson, 2007).

considerably greater (for the HadCM3 A1FI scenario, 94 and 25 people per km^2 for the good and poor accessibility zones, respectively). Interestingly, the domestic ruminant density is very similar: for the same GCM–scenario combination, 24 and 26 TLU per km^2 for the good and poor accessibility zones, respectively, although this then translates into nearly four times as many TLU per person in the good accessibility zone compared with the poor accessibility zone (3.9 versus 1.0 TLU per person). For these latter zones, average accessibility is now nearly 10 h, putting travel to the market well beyond what is feasible for a day-trip.

Perhaps the most notable characteristics of Table 3 are the substantial increases in the poverty proxies for the poor accessibility transition zones. For the good accessibility zones, these indicators are somewhat better than the continental mean values (lower infant mortality, stunting and wasting rates), but they are much worse for the poor accessibility zones. At the same time, there is relatively little variation between GCM–scenario combinations for the poverty proxies in the poor accessibility zones. This indicates that the areas of the MRA systems that are far from markets already have higher poverty rates than areas closer to markets. These results suggest that climate change impacts in these areas are likely to affect the poor disproportionately. Moreover, season failure rates also increase disproportionately: from just under 10% in 2000 for these transition zones, for both good and poor accessibility zones, to 22% for the good accessibility zones and to 25% for the poor accessibility zones, for the HadCM3 and A1FI combination. This is a telling increase in season failure—from 1 year in 10 to 1 year in 4, in the remoter transition zones.

Table 3 – Characteristics of the MRA transition zones (areas in the mixed rainfed arid–semiarid system that are projected to move from >90 RCGDs in 2000 to <90 RCGDs in 2050) for four combinations of climate model (Hadley CM3, HD; ECHam4, EC) and a higher- and lower-emission scenario (A1FI and B1, respectively), stratified by accessibility

	HD A1FI	HD B1	EC A1FI	EC B1
Good accessibility (<200[a])				
Area (km^2)	150,822	86,526	161,082	74,556
Human population, million (2000)	14.19	8.78	14.89	8.77
Cattle population, million	2.88	1.58	2.99	1.33
Sheep population, million	4.59	2.93	4.90	3.02
Goat population	3.25	2.16	3.46	1.98
Accessibility[a]	126	122	124	119
Infant mortality rate per 1000 births	84.0	80.0	85.0	75.0
Stunting rate (%)	29.5	29.3	30.0	27.1
Wasting rate (%)	22.6	22.4	23.5	20.6
Poor accessibility (>200[a])				
Area (km)^2	768,474	494,532	771,894	396,720
Human population, million (2000)	19.52	12.17	20.84	8.89
Cattle population, million	17.34	11.66	16.44	8.77
Sheep population, million	11.81	7.77	11.81	6.77
Goat population	12.70	7.76	12.62	6.53
Accessibility[a]	601	594	576	563
Infant mortality rate per 1000 births	97.0	97.0	97.0	99.0
Stunting rate (%)	36.7	37.3	36.4	35.9
Wasting rate (%)	29.7	30.3	29.6	29.3

[a] Minutes of travel time to a town or city with a population of more than 250,000 (Nelson, 2007).

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4. Discussion

There are several areas of uncertainty attached to such analysis. One relates to the definition of ‘‘transition zones’’, particularly the cut-off value used of 90 RCGDs. The sensitivity of the analysis to changes in this cut-off value is relatively muted: increasing this cut-off value by 11% (to 100 RCGDs) leads to an average increase in area of the transition zones of about 7% for the four combinations of GCM and emission scenario used. On the other hand, a 11% decrease in the cut-off value (to 80 RCGDs) leads to a decrease in area of less than 2% for the transition zones, compared with the 90-day cut-off value. This suggests that the results of the analysis are fairly robust, in terms of defining transition zones in which even the drought-tolerant crops such as millet are likely to become increasingly marginal and risky in the future.

Another area of uncertainty is associated with climate projections themselves and the unknown future forcing that will affect the composition of the atmosphere and the feedbacks from the land surface. Over the next four decades, global mean temperature rise is largely insensitive to differences among emission scenarios (Stott and Kettleborough, 2002). Nevertheless, it is clear that present and future predictability of climate variability and change 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), including projections of regional patterns of rainfall over large areas of Africa (IPCC, 2007). Tables 2 and 3 clearly indicate that there are substantial differences in the size of the MRA transition zones depending on the scenario used; there may also be sizable differences depending on the GCM used. More information on the sensitivity of the results could be garnered by using a larger number of GCM and scenario combinations for the analysis (there are 20 such combinations, arising from five GCMs and four SRES scenarios, in the full dataset of Mitchell et al. (2004), for example). Nevertheless, while we do not know what the future levels of GHG emission will be in the coming decades, even the lower-emission scenario used in this analysis indicated that substantial agricultural adaptation may be required to offset the negative impacts on livelihoods in some of the marginal areas of sub-Saharan Africa.

A further problem area is our limited 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. While this downscaling can of course be done, its adequacy cannot currently be evaluated objectively (Henderson-Sellers, 2007). Nevertheless, there are various methods for more sophisticated downscaling of GCM outputs than those used here (for an extensive review, see Wilby et al., in press), and for particular sites that have appropriate historical climate data, some of these tools could provide some information on the scale of the uncertainties inherent in more localised climate scenarios. As Wilby et al. (in press) note, while there are substantial knowledge gaps there are also significant opportunities for improving the production and evaluation of higher-resolution climate change scenarios, particularly those aimed at providing risk information for the medium term (the 2020s, for example). There is still a lot of work to do in this area, however.

At the same time, adaptation work in developing countries has very specific and detailed information needs in order to be able to assess the likely impacts of different interventions and to target particularly vulnerable people. For agencies pursuing mandates that are pro-poor, vulnerability decreasing and food-security-enhancing, for example, aggregated or low-resolution assessments are unlikely to be able to inform their research and development agendas adequately. Even regional studies will miss much of the local detail that is ultimately required, and in terms of being used to guide investments in adaptation work, we would argue that priorities will depend on who (exactly) and where (precisely) are the highly vulnerable populations, rather than on the risk attitudes of potential investment institutions (Lobell et al., 2008). There is currently a mismatch between the kind of localised climate change impact information that is urgently needed, and what can objectively be supplied. It is clear that the underlying climate science and models will have to be improved, and that different regionalisation techniques will need to be developed, evaluated and improved (Henderson-Sellers, 2007).

For these and other reasons, the results presented above should be taken as indicative only. Nevertheless, the analysis is suggestive of points that warrant further elucidation. One is, that a breakdown of the impacts of climate change on the basis of prevalent agricultural systems is just one step along the road of higher-resolution targeting of different adaptation options. However, results with the simple transition zones identified above indicate that areas that are already marginal for cropping are likely to become increasingly marginal, and that the people who depend for their livelihoods in these marginal areas are already much poorer than average. The analysis also suggests that populations in more remote marginal areas will be disproportionately affected by climate change—as these impacts take hold, the poorest will be the worst affected, all other things being equal. In such situations, in which climate change impacts will tend to negatively affect the production potential of areas where particularly poor populations are located, the problems of climate change may perhaps best be addressed within the short-term framework of risk management proposed by Washington et al. (2006), which depends on a close engagement with climate variability.

The type of analysis presented here should be able to provide some insight into helping research and development organisations target adaptation options. In recent years, the notion of poverty reduction as one of the driving forces for international agricultural ‘‘research for development’’ agendas has prompted several attempts to render priority setting and targeting much more specific to the different ways in which people in different situations might be able to move out of poverty. This targeting will often need to take account not only of biophysical factors but also of things such as the age and gender of the decision-maker and his or her socio-economic status, for example (Campbell, 1999). The matching of appropriate technical and policy interventions with appropriate target populations might usefully be done in relation to different typologies of such factors. Different frameworks have been developed for this purpose. For example, Perry et al. (2002) identified three sometimes-overlapping ‘‘pathways out of poverty’’, originally in relation to livestock disease research in South Asia and Africa:

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- Securing the current assets (human, financial, and social) of poor people who are dependent on natural resources directly or indirectly for a substantial part of their livelihood, by reducing the financial, climatic and disease-related risks they experience.
- Enhancing the marketing opportunities of the poor, for example by reducing the costs of market participation, increasing access to markets and market information, and controlling the diseases that may limit the marketing of livestock products.
- Enhancing the ability of the poor to improve productivity and performance efficiency through the use of inputs and thus intensify their production systems.

Some of the transition zones characterised in Table 3 can be related to one or other of the pathways in this schema. For example, efforts aimed at controlling specific livestock diseases associated with intensifying systems could be envisaged in the good accessibility transition zones—mastitis in smallholder dairy systems that involve cross-bred animals is one example. On the other hand, strategies that may be more appropriate for the poorer accessibility areas of the transition zones may have much more to do with securing assets. An example is livestock insurance schemes that are index-linked to some factor such as weather or local livestock mortality rates (to avoid the creation of some of the perverse incentives that have affected traditional crop insurance schemes), and which can be made accessible to the poor, perhaps through the participation of smallholder farmers' groups and the provision of collateral through 'social capital' (UNDP, 2008).

Another framework is that of Dixon et al. (2001), which identifies several types of strategy that households can engage in to improve livelihoods, including diversification through increased off-farm income and exit from farming. This provides expert estimates of the potential and relative importance of these and other strategies for households to reduce poverty in the different farming systems of Africa at a broad scale. The type of analysis undertaken here could add detail and local context to these assessments. Options for increased off-farm income are likely to be much more feasible for households that have good accessibility, for example.

What this spatial analysis can bring to bear in targeting work is not so much increased understanding of the key processes involved (that may come from many other different sources) as detail and some local context in terms of who may be affected, how, and where. The transition zones identified in Fig. 3 are very patchy, quite numerous, and often rather small in area. This goes somewhat beyond the usual notion of recommendation domains as relatively large, spatially contiguous areas that share common characteristics. This type of analysis can thus start to address the considerable spatial variability associated with both the impact of climate change and different households' ability to deal with this impact. We envisage that this kind of more nuanced targeting information could be of considerable value to research and development organisations with a specific focus on poor and highly vulnerable people.

There is, however, much work to do to better define pathways out of poverty, and how these may be related to specific spatial and non-spatial characteristics. This area of work is still in its infancy, partly but not entirely because of the perennial problems of data availability at appropriate scales. Given the heterogeneity of smallholders' farming systems and access to resources, considerable detail is required if targeting work is to be effective. Ultimately, such targeting work needs to be able to provide information on the ''limits to adaptation''—the point at which households and farming systems become so stressed that there are few alternatives to an exit from farming. Identifying the factors that define these limits to adaptation, and the triggers that may precipitate abandonment of livelihood dependence on natural resources, are key issues in the marginal systems in the coming decades that development agencies and governments alike will need to address.

5. Conclusions

Under even a moderate GHG-emission scenario for the coming decades, there are likely to be substantial shifts in the patterns of African cropping and livestock keeping to the middle of the century. Potential livelihood transition zones can be identified, and they can be distinguished in terms of characteristics such as their accessibility that may have considerable impacts on the type of adaptation options that may be viable: for those that are relatively close to large human settlements, for example, there may be options for both integration of livestock systems into the market economy and for off-farm employment opportunities; for those that are more remote, both market and off-farm employment opportunities may be much more limited. There are currently significant populations of people in these more remote transition zones, and they are widely spread throughout West, East and southern Africa. The results reported here suggest that substantial changes may be required to people's livelihood and agricultural systems if food security is to be improved and incomes raised. Climate change impacts in some of the marginal cropping lands of Africa are likely to be severe, and poverty rates in these areas are already high. Results of this analysis suggest further that the poor in the more remote transition zones are likely to be disproportionately affected.

The kind of analysis presented here should be able to help in implementing highly targeted schemes for promoting livestock ownership and facilitating risk management where this is appropriate, as well as in efforts to broaden income-generating opportunities in parts of the continent where this is feasible. The work highlights the critical need in priority setting and impact assessment to take account of likely impacts of climate change and variability on future systems. Taking account of climate change may lead to substantial adjustments in research portfolios and changes in the location of technology testing sites. Considerably more high-resolution work is needed to improve our understanding of the likely impacts of climate change on agricultural and livelihood systems. This will require at least two things: localised climate data for future scenarios that can be objectively evaluated, and higher-resolution databases that more accurately describe the local conditions and context of farming systems.

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