CLIMATE CHANGE IMPACTS ON AFRICAN RANGELANDS

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Introduction

Even though Africa has contributed the least to global greenhouse gas emissions, it is considered the continent most susceptible to climate change impacts because of: (1) the large proportion of people who live in the sub-tropics which will be most affected by increased temperature and reduced precipitation; (2) the high dependence of people on natural resources, livestock and agriculture for their livelihoods; (3) extreme poverty in many parts of Africa which makes it difficult for affected people to respond to an increased incidence of drought and floods and (4) the degraded state of Africa's natural resources which renders them less resilient to the impact of higher temperatures and lower and more variable precipitation (Hein, 2006; Boko et al., 2007; Christensen et al., 2007; Easterling, et al., 2007).

We first describe the extent and importance of Africa's rangelands as well as the climate change projections for the continent and the likely response of rangelands to these changes over the next 100 years. We then reflect briefly on some of the complex interactions between people and the environment. Finally, we summarize some possible responses that could enhance Africa's ability to adapt to climate change.

Africa's rangelands and their importance to the continent

Africa covers about 30 million km^2 and while it is slightly smaller in size than Asia it is unique in having its land mass distributed more or less equally in both hemispheres. Its vast length (8050 km), breadth (7560 km) and altitudinal range (-153 m to 5895 m above sea level) (Elasha et al., 2006) results in tremendous variability across the continent driven by several large, complex atmospheric features (e.g. the West African Monsoon, the Intertropical Convergence Zone and the El Niño-Southern Oscillation (Christensen et al., 2007; Conway, 2008). These weather systems influence the size and functioning of the major land cover classes on the continent from daily to millennium time scales (Table 1, Figure 1) and interact with each other in complex ways which are not well understood at present.

[INSERT FIGURE 1]

Africa's rangelands are comprised mostly of the Woodlands/Shrublands and Grasslands land cover classes (43% of Africa or nearly 13 million km^2) (Table 1) although a significant amount of livestock production also occurs within the agricultural lands and some also on the margins of Bare Soil environments, particularly during above average rainfall years. Their composition and productivity are influenced primarily by rainfall, fire and grazing (Fischlin et al. 2007) although over longer time frames, changes in temperature and the concentration of atmospheric CO$_2$ are also important.

A wide range of land use systems, governed by often complex land tenure arrangements affect Africa's rangelands. Within this complexity, Thornton et al. (2006a) identified three main types of livestock systems: (i) Industrial livestock systems, (ii) Agro-pastoral and pastoral systems, (iii) Smallholder crop-livestock systems. Irrespective of the system used, however, livestock are central to the livelihoods of more than 200 million Africans who rely on them for income from sales of milk, meat and skins, for protein consumption, draught power, ritual and spiritual needs, amongst other uses. Owning livestock is one way in which many people are able to diversify their risk, increase their assets and improve their resilience to sudden changes in climate, disease outbreaks and unfavorable market fluctuations (Thornton et al., 2006a).

Table 1. The area of Africa's land cover classes (000 km^2) based primarily on vegetation structure (from Mayeux et al. 2003). The major rangelands in Africa are to be found in Woodlands/shrublands and Grasslands land cover classes.

Region	Dense forest	Mosaic forest/ Croplands	Woodlands/ shrublands	Grasslands	Agriculture	Bare Soil	Wetlands
Central Africa	2034	541	1367	300	250	702	156
East Africa	72	151	1263	1796	1162	1589	45
North Africa	5	0	175	458	167	5119	0
Southern Africa	90	7	3013	2085	672	201	46
West Africa	104	476	1084	897	739	2352	27
Madagascar	55	104	159	261	0	0	3
Africa	2359	1279	7061	5797	2989	9963	277
%	7.9	4.3	23.8	19.5	10.1	33.5	0.9

Agricultural production (of which livestock production is an important part) not only contributes to the livelihoods of individual households, but also to the continent's economy as a whole. It accounts for 20-30% of the Gross Domestic Product of sub-Saharan Africa and 55% of African exports (Elasha et al., 2006). Despite rapid rates of urbanization, more than 60% of Africans still live in rural areas, and more than 56% of the total labor force (estimated at over 200 million people) were engaged in some form of agricultural activity in 2002 (UNEP, 2006). Estimates are that nearly 90% of the poorest inhabitants work primarily in agriculture (Elasha et al., 2006) and more than two thirds own livestock (UNEP, 2006) although de-agrarianisation and diversification into other activities have been noted (Bryceson, 2002, 2003).

Despite the natural and mineral riches of Africa, nearly 60% of the continent's 812 million people live on less than US$1 a day and the proportion of people living below the poverty line increased in the last 15 years of the 20th century (UNEP, 2006). Even though Africa spends up to US$20,000 million each year on food imports (in addition to the US$2,000 million it receives annually in food aid), about 26% of the population are undernourished (UNEP, 2006). Given recent global climate change projections (IPCC,

2007) it is appropriate to investigate the likely impact of such changes on the continent's rangeland resources and on the people who use them.

Climate change over Africa's rangelands

Historical trends

Similar to global trends, Africa warmed by about 0.5°C in the 20th century with the most rapid warming occurring between 1910-1930 and after 1970, particularly in southern and northern Africa (Hulme et al., 2001; Christensen et al., 2007). Rainfall trends and patterns are more difficult to determine and significant regional differences are evident. For example, the alternating wet and dry periods in the Sahel, particularly the dry period after 1970, have been studied in detail (Brooks, 2006; Boko et al., 2007). There is some evidence that rainfall increased in parts of eastern Africa during the 20th century (Hulme et al., 2001; Christensen et al., 2007). Other areas of the continent, such as Southern Africa have experienced marked inter-decadal variability (Christensen et al., 2007) which adds to the difficulty of managing complex risks in several African environments.

Detailed local-level analyses of the historical rainfall record have indicated that the patterns are spatially complex, particularly in mountainous terrain, and the scale of observation and density of climate stations can influence the outcome significantly. For example, Mackellar et al. (2007) have shown from the relatively comprehensive historical rainfall record for rangelands in Namaqualand, South Africa, that some areas, which have exhibited a significant increase in rainfall since 1950, can abut areas only 50 km away, which have shown a significant decrease.

Furthermore, the biological composition and functioning of rangelands are not only influenced by climate. Local land use practices such as cultivation, heavy grazing, resource extraction (e.g. firewood use) have a profound influence on African rangelands (Hoffman and Ashwell 2001) with significant feedbacks on some important drivers of climate (Christensen et al., 2007). A closer alignment of historical climate data with comprehensive land use histories is urgently needed to understand the full extent of changes that have occurred in African rangelands over the course of the 20th century (see Text Box 1).

Future climate projections

What are the future climate change projections as they affect Africa's rangelands in the 21st? The comprehensive analysis in the 4th IPCC Assessment Report (Christensen et al., 2007) forms the basis for this summary. In this context, the phrases 'very likely' and 'likely' which are used below, refer to a probability of occurrence of >90% and >66% respectively (see Bernstein et al., 2007: 27).

- Atmospheric concentrations of CO_2 have increased by more than 100 ppm since industrial times and will increase further from the current 380 ppm to about 520 ppm by 2100 if 2000 emission rates continue (Meehl et al., 2007). Atmospheric CO_2 concentrations measured in 2005 have not been experienced on Earth for 650,000 years (Bernstein et al., 2007), and will influence significantly the physiology and competitive interactions of rangeland plants.

- Temperature will increase by between 2-6°C by the end of the 21st century (Conway, 2008) depending on the region and SRES emission scenario used (Christensen et al., 2007). Increases will very likely be greater throughout Africa and in all seasons than the global average with the drier northern and southern Africa subtropical regions warming more than the moister tropical regions of western, central and eastern Africa as well as the coastal environments (Christensen et al., 2007).

- Annual rainfall is likely to decrease in southern and northern Africa with the mediterranean areas of both regions being particularly badly affected. It is likely, however, that rainfall could increase in eastern Africa. Model projections for the Sahel, the Guinean Coast and the southern Sahara have returned mixed results and are considered unclear at present (Christensen et al., 2007).

- Changes in variability (e.g. periods of extended dry spells, wet spells, pattern of rainfall including numbers of rain days, etc) is an additional area of concern. While limited by the number of studies and data to support very conclusive statements on trends at present, emerging research shows that droughts are likely to increase in total area affected and that heavy precipitation events are likely to increase generally beyond that expected from changes in the mean (Boko et al., 2007; Christensen et al., 2007). More than 250 million Africans live in drought-prone areas (Elasha et al., 2006). Changes in the frequency and magnitude of drought may add to the complex risk-management portfolios that many people use to sustain their livelihoods and such changes will make recovery more difficult as periods between significant events will be shortened.

- There is considerable uncertainty associated with these projections. This uncertainty has arisen in part because a growing, but nonetheless limited understanding of the key drivers of African climates (Conway, 2008) that is frustrated by poor data and monitoring sources and further complicated by trying to understand the web of interaction between climate, land cover/atmospheric feedback processes (Christensen et al. 2007) and dust and biomass aerosols (Hulme et al., 2001). For example, depending on the scenario and model used, different GCM results for rainfall changes in the West African Sahel range from +15 to -50% (Hein 2006). There is also uncertainty as to whether the Sahara is going to get wetter or drier or what the impact of climate change is likely to be on the Nile River system and on African agriculture in general (Conway, 2008). A comparison of the maps of projected climate change impacts on the vegetation of Africa produced by Thornton et al. (2006b) and Fischlin et al. (2007) is a sobering reminder of the high degree of uncertainty in environmental responses to global warming.

Implications of climate change for Africa’s rangeland resources and ecosystem services

The changes outlined above will have a range of impacts for people, particularly those who derive a large portion of their livelihoods from rangelands. Such changes in climate may also compound other changes that are already taking place (e.g. changes in access in to resource use, urbanization) and in some areas, may also enhance livelihoods. Some of the likely impacts, arising from changes in Arica's climate, are outlined below.

Change in water resources

The impact of climate change on Africa's hydrological resources has been shown using a range of GCM projections (de Wit and Stankiewicz, 2006). Three main hydrological regions (dry, intermediate, wet), based on their perennial drainage densities (total perennial stream length per unit area), were identified in this analysis. The results show that it is in the intermediate region receiving between 400-1000 mm of rain per year that the impact of climate change on surface drainage will be greatest. The impact will also be felt non-linearly and drier areas within this range will experience significantly greater losses in surface drainage with a decrease in rainfall than wetter areas. For example, a 10% drop in rainfall (which is well within the bounds projected for southern Africa) in a region of 1000 mm per year will result in a decline in surface drainage of only 17% while in areas of 500 mm per year the same decrease in rainfall will result in a 50% decline in surface drainage. Such a dramatic response in surface drainage to decreasing rainfall could have devastating consequences for this intermediate hydrological zone which covers 25% of the continent, affects 75% of the 48 mainland countries in Africa and includes most of the densely populated savanna rangelands of southern and eastern Africa and a significant part of the Sahel (de Wit and Stankiewicz, 2006). The decrease in surface drainage coupled with an increase in water demand by livestock and people, as a result of increased temperatures (Thornton et al., 2006a) will challenge traditional coping strategies and likely increase tensions around already scarce water resources.

Change in rangeland productivity

Rainfall and temperature are key determinants of rangeland productivity. The effect of future climate change projections on the length of the growing period (LGP), which integrates the influence of temperature and rainfall on productivity, results in a number of potential impacts, including changes in the length of the growing season for certain agricultural activities (Thornton et al., 2006b). Using the downscaled outputs of the HadCM3 and ECHam4 under a range of SRES scenarios, changes in LGP to 2050, relevant to current conditions, were computed for Africa. While there was considerable variation in the outputs, generalized findings were that the combined impact of changes in temperature and rainfall will result in a decrease of LGP in much of sub-Saharan Africa and in some cases this decrease will be severe (Figure 2). Areas where decreases in LGP >20% are predicted consistently include large parts of southern Africa, particularly where cropping is marginal, as well as a broad swathe in the Sahel, in the ecotone between the savanna and desert biomes of the northern African sub-tropics. A significant reduction in LGP by 2050 was also predicted in most models for the more arid parts of eastern Africa (Thornton et al. 2006b).

[INSERT FIGURE 2]

Fischlin et al. (2007) used a similar approach in their analysis of “projected appreciable changes in terrestrial ecosystems by 2100 relative to 2000…” While there are clear similarities between their map and the map of Thornton et al. (2006b) there are also appreciable differences. In general, Fischlin et al. (2007) suggest a far more benign future for Africa’s rangelands with considerable portions of the subtropics showing an increase in forest, woodland and herbaceous cover. Even the more arid southern African region is predicted to experience conditions described as “desert amelioration”. Reasons for the discrepancies in the two outputs are worth investigating and underscore the high degree of uncertainty associated with future projections.

The links to other climate phenomenon, particularly those most often associated with climate variability, such as El Niño-Southern Oscillation (ENSO), have also been examined for agro-pastoral production in Africa (Stige et al., 2006). Results here suggest reduced food production including the productivity of crops, livestock and pastures in Africa, if the frequency of ENSO-like conditions increases.

Change in forage quality and rangeland composition

Temperature, rainfall and atmospheric CO_2 concentration interact with grazing and land cover change to influence rangeland quality and composition. Increased temperature, for example, not only increases drought stress in plants but also increases lignification of their tissues which affects both its digestibility as well as its rate of decomposition (Thornton 2006a). Increased temperature and lower rainfall also increases vegetation flammability (Fischlin et al., 2007) resulting in a shift in species composition as a result of an increased fire frequency. The amount and timing of rainfall on its own, also has an important influence on rangeland species composition in both the short- and long-term, primarily through its differential effect on the growth and reproduction of key forage species. An extended drought can result in the mortality of perennial plants and the switch to an annual-dominated flora (Hein, 2006).

Atmospheric CO_2 is fundamental to the efficient physiological functioning of plants primarily through its influence on photosynthesis and nutrient absorption. Because of this, any change in CO_2 concentration affects the performance and competitive ability of plants. Plants generally use less water at higher CO_2 concentrations and a reduction in transpiration means that more water is available in the soil. Bond et al. (2003) suggested that a doubling of CO2 could nearly double the effectiveness of rainfall.

While C3 grasses should benefit more from increased CO_2 concentrations than C4 grasses, experimental results are far from conclusive (Wand et al., 1999). Both pathways appear to benefit from CO_2 enrichment and growth rate is more important than a plant’s biochemical pathway in predicting its response to CO_2 (Poorter and Navas, 2003). Just to complicate matters, recent findings suggest that warming and CO_2 could have opposite effects on C3 and C4 plants with the former favored by CO_2 and the latter by increased temperature (Fischlin et al. 2007).

Bush encroachment occurs as a result of the invasion of shrubs and trees into previously grassy rangelands. It is a common phenomenon in Africa and usually results in an increase in biomass but a decrease in rangeland productivity. The projected increase in the concentration of atmospheric CO_2 could enhance the process of bush encroachment in two important ways. Firstly, less transpiration could result in more plant available water, particularly at depth, where deeper-rooted trees and shrubs have their roots. Greater access to water could increase the length of their growing season and increase their competitive dominance to the exclusion of shorter growth forms such as grasses and perennial herbs. Another mechanism for the increase in bush encroachment suggests that an increase in CO_2 results in faster growth rates of saplings (Bond and Midgley, 2000). This enables them to more quickly escape the height at which fire usually kills young trees. Bond et al. (2003) have modeled the wider implications of this process and suggest that changing CO2 concentrations over the last 12000 years could explain the expansion and contraction of southern African savannas over this period.

Change in land use systems and rangeland-based livelihoods

The general reduction in productivity which is projected for Africa's rangelands will have important negative consequences for the development potential of an area and will likely result in a shift in sectoral activities (Hulme et al., 2001; Easterling et al., 2007). Some projections suggest that in marginal crop production areas the decrease in the length of the growth period (LGP) and an increase in rainfall variability will render cultivation too risky and will result in a switch to more rangeland-based, livestock production systems (Thornton et al. 2006a). There is also likely to be a switch to breeds and species (e.g. from cattle to sheep, goats and camels) which are better adapted to more marginal conditions (Hulme et al. 2001; Easterling et al., 2007). Other changes include a greater frequency of loss of livestock assets particularly through drought and through an expansion of vector-borne (e.g. ticks) diseases into cooler areas (Thornton et al., 2006a), a reduction in income and increased income inequalities and a general reduction in livelihood security for people who derive their livelihoods primarily, or even in part, from Africa's rangelands (Easterling et al., 2007).

However, reducing all changes in rangelands only to climate change as a 'driver' of change is well known as being a gross over-simplification. Recent assessments in parts of Africa (e.g. Archer, 2004 and Herrmann et al., 2005), for two contrasting areas (namely the African Sahel and eastern Karoo, South Africa), showed that land cover changes in both cases was not only determined by rainfall changes but also by complex rangeland management decisions. Climate (e.g. temperature and rainfall) is important but the combined impact of grazing and stocking strategies, and other factors influencing decision making, are also key in shaping rangelands (Batterbury and Forsyth, 1999; Brooks, 2006). Rather than singular stresses shaping and dominating the environment a range of other factors also need to be understood including the interaction of human settlements and changes in land use as well as how various policies impact on land use change. Much more work is also required on how policy and understandings of rangeland changes are framed, reproduced and mainstreamed into practice (e.g. Batterbury and Forsyth, 1999; Homewood, 2004, Rohde et al., 2006; see also Text Box 1). These various interactions can act as critical drivers of rangeland bringing with them potential changes including conflicts between different land use sectors.

Mapping vulnerability

The most comprehensive, spatially-explicit analysis of the impact of climate change on Africa's rangeland and its communities has been conducted by Thornton et al. (2006b) as part of DFID's research program on climate change and development in sub-Saharan Africa. Building on their climate change hotspot analysis (Figure 2) they developed a final set of four components of vulnerability, derived from an initial fourteen 'proxy indicators' which were associated with natural, physical, social, human and financial capital in the region. They identified "*…the mixed arid-semiarid systems in the Sahel, arid-semiarid rangeland systems in parts of eastern Africa, the systems in the Great Lakes region of eastern Africa, the coastal regions of eastern Africa, and many of the drier zones of southern Africa*" (Thornton et al., 2006b: 3) as being the areas on the continent most vulnerable to climate change.

Management and policy implications

Given that Africa will be particularly negatively affected by climate change, what steps can be taken to mitigate and adapt to its impacts? Firstly, we need to know more about how African rangelands have responded to changing climates in the past and how land use practices have combined with climate change to influence the production and composition of these systems (see Text Box 1). Climate change projections largely ignore the complex inter-play that exists between people, their environment and the linked urban-rural societies in which they live (Batterbury and Forsyth, 1999; Homewood, 2003, Boko et al., 2007). The extent and rate of past environmental change and an understanding of the reasons for such changes is required.

Secondly, and somewhat related, we also need to develop better monitoring systems both of climate and of ecosystem response and we need to expand our capacity as Africans, through collaboration with international initiatives and agencies, to conceive, fund, implement and manage such monitoring programs. Several major climate change adaptation-relevant initiatives and activities are already underway in Africa (Elasha *et al*., 2006; Boko et al., 2007). A number of donor-driven activities as well as various institutions have also been established to address the role of such activities in shaping rangelands (e.g. the origins, outcomes and processes of engagement of such activities (Peet and Watts, 2004).

Thirdly, we need to intervene to lessen the impact of climate change on Africa's most vulnerable communities. A broad-based typology of responses to climate change has been developed by Kurukulasuriya and Rosenthal (2003). Their framework provides a comprehensive approach to intervention and includes ideas for micro-level adaptations and technological developments as well as market responses and institutional and policy changes. While this is an excellent starting point for any intervention strategy, knowing what approach could be used most effectively in which area is an important first step in knowing how to deal with the impact of climate change (Thornton 2006a) and a greater understanding of the complex interactions in various areas is also required.

Finally, Africa's rangelands are dominated by extensive livestock production systems and securing these assets particularly for poorer households in the face of climate change is a major challenge. Some of the most important suggestions for how to do this focus on enabling herd mobility through securing better access to water resources and increasing access to more land, particularly when it is marginal for crop production (Hesse and Cotula, 2006; Thornton et al. 2006a). Other suggestions include the improvement of early warning systems and dissemination of this information, enabling pastoral groups to better engage with policy debates, building stronger conflict management institutions and supporting a diversification of livelihoods, perhaps through tourism and conservation (Hulme et al. 1996; Hesse and Cotula, 2006). The non-equilibrium perspective around development thinking contained in Scoones (1995) is a useful paradigm to follow in this regard.

It should be remembered, however, that the impact of climate change is not the only factor that will affect livestock production on the continent and the rangelands which sustains these activities. While these impacts should not be ignored, they should also not be exaggerated (Hulme et al., 1996). High population growth (estimated at 1.9% between 1992 and 2002), rapid rates of urbanization (up to 3.5% per annum in some countries), land reform initiatives, and the high mortality of agricultural workers from HIV/AIDS (which could be as high as 26% in badly affected countries in the next two decades) are only a few of many other factors which will influence Africa's agricultural environments, including her rangelands, in the 21st century. Climate change impacts may also not all be negative, and a better understanding of where and why responses have been successful (e.g. Nyssen et al., 2007), is also required.

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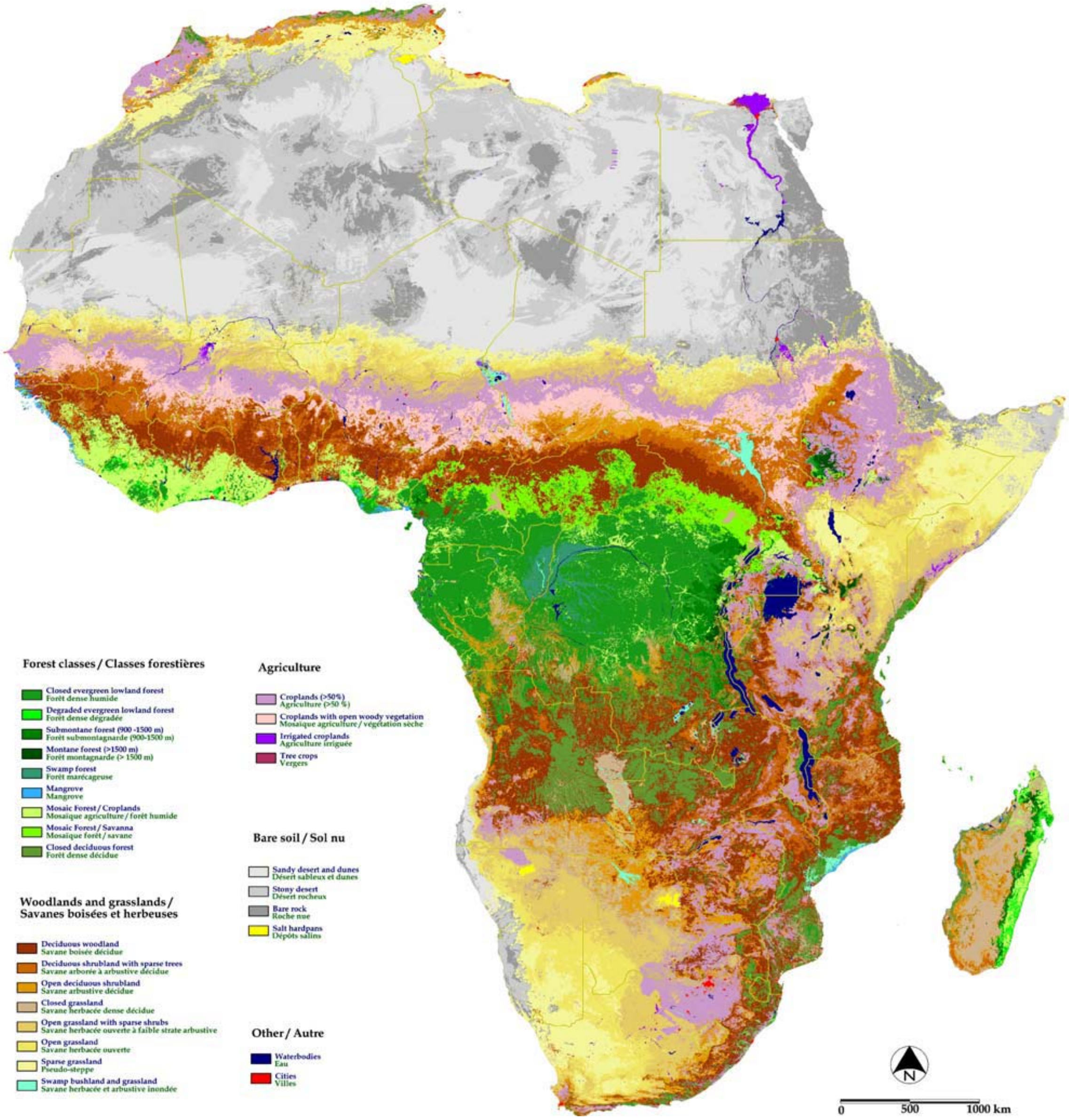

Figure 1. Land cover in Africa (from Mayeux et al. 2000).

[THERE ARE UNDOUBTEDLY COPYRIGHT ISSUES IN USING THIS MAP. I NEED TO LOOK AT THEIR GLC2000 WEBSITE AND AGAIN AND MAKE SURE OF THIS].

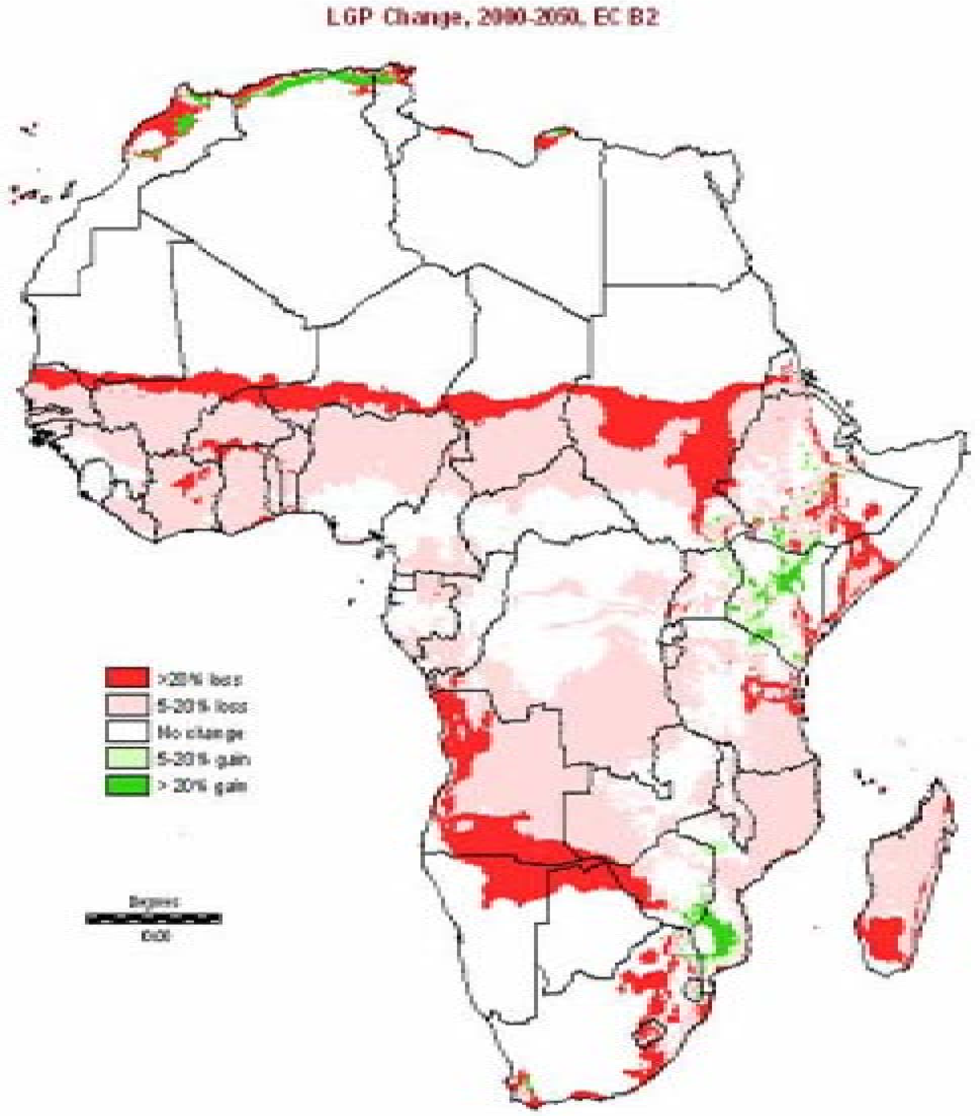

Figure 2. Percentage changes in length of growing period to 2050, ECHam4 and scenario B2. (Fig 7(B) Thornton et al., 2006b).

[COLEEN WILL GET PERMISSION FROM PHILLIP THORTON TO USE A HIGHER RESOLUTION COPY OF THIS MAP.]

Text Box 1: Africa’s environmental history and the impacts of climate change

Detailed inspection of the historical climate record suggests that African temperatures have increased by 0.5°C over the course of the 20th century and that rainfall has decreased in some parts but not in others (Hulme et al., 2001; Christensen et al., 2007). Most future projections paint a gloomy picture for African rangelands (Conway, 2008). But how have they changed over the course of the 20th century in response to the key drivers of climate and land use and what does this tell us about likely future changes?

While Africa’s drylands are considered some of the most degraded in the world (Middleton and Thomas 1997; Reynolds and Stafford-Smith, 2002), several historical studies contest the litany of environmental destruction in Africa (Leach and Mearns 1996). These include:

- West Africa: Fairhead and Leach (1996) reappraised the pattern and direction of vegetation change within the forest-savanna mosaic around Kissidougou (Guinea) and showed that in some cases forests are not relics of destruction but have been created by people around their settlements.

- East Africa: A 30-year study in northern Ethiopia by Jan Nyssen and his colleagues (Nyssen et al. 2007) showed how erosion has decreased and how hydrological function, vegetation cover and agricultural production have all improved as a result of better management of natural resources in the region (see also Tiffen et al., 1994).

- Southern Africa: A series of repeat photographs which document environmental change in semi-arid Namaqualand has shown an increase in vegetation cover at many sites including riverine areas following a reduction in livestock and an abandonment of marginal agricultural lands (Hoffman and Rohde, 2007) (see also Rohde, 1997).

These studies all describe an ‘improvement’ in rangeland condition and plant cover despite increases in temperature and human populations over the course of the 20th century. They emphasize that climate change projections alone are not enough to build an understanding of what Africa’s rangelands will look like in the future. The litany of future environmental collapse needs to be balanced with well-documented environmental histories which track change over time and provide benchmarks for understanding the rate and extent of future change.